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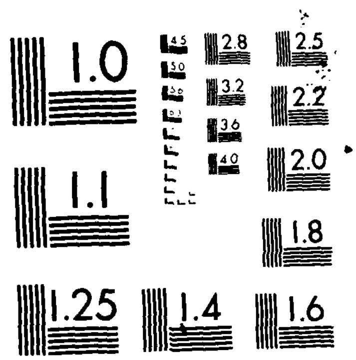

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AD-A172 449

TERRAIN-MODELING METHODOLOGY FOR AIRCRAFT ENCOUNTERS WITH SURFACE-TO-AIR MISSILES

THESIS

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AFIT/GST/ENS/86M-10

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TERRAIN-MODELING METHODOLOGY FOR AIRCRAFT ENCOUNTERS WITH SURFACE-TO-AIR MISSILES

THESIS

QUALITY INSPECTED 4

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science

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by

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Ronald G. Johnson, Major, USAF
Graduate Strategic and Tactical Sciences

March 1986

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In performing this research we received a great deal of help from others. Mr. David Richart and Mr. Jordan Wescott, both from the Engineering Branch of Aeronautical Systems Division, provided detailed information on Digital Terrain Elevation Data, programming software to access and manipulate that data, and considerable technical advice. Without their assistance, this research effort would not have been possible. Major James Coakley, formerly of the Operational Sciences faculty, provided substantial assistance in initially focusing this research effort. Finally, we would like to thank out faculty advisor, Captain Joseph Litko, who provided valuable insights and guidance during the course of this study.

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Abstract

The objective of this research was to develop a methodology to characterize entire terrain types in terms of their impact on the encounter between aircraft and surface-to-air missile (SAM) systems. Two contrasting types of terrain were chosen for analysis, the moderately rugged terrain around Fulda, West Germany, and the North German Plain. Digitized terrain elevation data (DTED), developed by the Defense Mapping Agency, served as raw data. Twenty suitable SAM sites were sampled from each terrain area. Four layers of data transformation were used to convert the DTED data for these sites into 49-cell terrain models. These terrain models consisted of probability distribution functions of masked and unmasked distances an aircraft would fly as it transitted a SAM system's lethal zone at various altitudes. A simulation model was then used to determine the number of completed engagements an aircraft would experience per nautical mile flown through a battle area in each terrain type. The simulation runs used five variables: aircraft altitude, aircraft airspeed, threat density, missile speed, and SAM system reaction time. A full factorial design analysis of variance was then accomplished to determine what the significant factors were, and to explain how they interacted to define terrain effects on the aircraft-SAM system encounter. Multiple regression was used to develop a single equation that predicts terrain effects in each terrain type in terms of an upper bound on the number of complete engagements possible per nautical mile. The resulting regression equations have extremely high predictive capability, and would be usable in more complex models to define the effects of terrain on the aircraft-SAM system encounter.

TERRAIN-MODELING METHODOLOGY FOR AIRCRAFT ENCOUNTERS WITH SURFACE-TO-AIR MISSILES

I. Introduction

Surface-to-air missile (SAM) systems are serious threats to even the best equipped and best flown aircraft. For instance, the Soviet SA-6 SAM system took a heavy toll on Israeli aircraft during the 1973 Arab-Israeli War, possibly destroying as many as 35 aircraft in the first afternoon (14:20). As a countermeasure to SAMs, pilots normally plan to penetrate enemy air-defenses at low altitude, where intervening terrain features can mask their aircraft from the field of view of enemy radars. The term commonly used to describe this tactic is "terrain masking," and it may result in the aircraft being concealed from enemy radars for substantial periods of time, even without conscious effort by the pilot. This tactic is significant because many other countermeasures, such as electronic jamming, may not be effective against modern Soviet SAM systems, such as the SA-8 (23:18-19). Because terrain masking may a decisive factor in real-world encounters between aircraft and SAM systems, Air Force pilots are thoroughly trained in terrain masking techniques. Therefore, the effect of terrain in aircraft-SAM encounters must be modeled and well understood by military mission planners and analysts.

Unfortunately, terrain effects on the outcome of encounters between aircraft and SAM systems are difficult to model. The result of each encounter is dependent on the unique characteristics of the terrain surrounding a specific SAM site location. These unique terrain characteristics are not easily generalized into a form that can be used

by a model that simulates encounters occurring at random locations. Previous terrain modeling attempts have focused on the terrain around specific SAM sites. While these site-specific models are useful for planning a particular mission, flown over a certain ground track, they cannot be used in a generalized form in a generic planning model.

Problem Statement

Current models of the aircraft-SAM encounter are site-specific, and do not effectively account for generalized terrain factors.

Objectives

The purpose of this thesis is to develop a methodology to quantitatively characterize terrain effects, generalize these effects to apply to an entire geographic area or terrain type, and then incorporate these terrain effects into a model of the encounter between aircraft and SAM systems. Secondly, this study seeks to determine what factors influence the impact of terrain on the aircraft-SAM encounter. That is, how do variations in such factors as aircraft altitude or airspeed change the outcome of the encounter when terrain effects are included? Finally, this research seeks to apply the derived terrain modeling methodology to two different types of terrain, to gain insight on variations in the impact of terrain effects.

Limitations

Parent Models. This study focuses as strictly as possible on the role of terrain in aircraft encounters with SAM systems. Parent models at such defense agencies as HQ USAF Studies and Analysis already account for most of the other aspects of the aircraft/SAM encounter, such as the Probability of Successful Missile Launch, Probability of Successful

Missile Guidance, and Probability of Accurate Warhead Detonation (18). This study assigns these probabilities a value of one, so that the output of the terrain effects model can be used as an independent input to these parent models. The ultimate measure of merit developed here, number of completed engagements per aircraft per nautical mile, provides these parent models with a versatile measure of the upper bound on the number of completed SAM engagements that a particular terrain type will allow.

SAM System Types. This research effort deals only with SAM systems that use semi-active homing or command missile guidance. Such systems require virtually continuous line-of-sight between the SAM system ground radar and the target throughout the encounter. Semi-active homing systems require line-of-sight to ensure constant target illumination, and command guidance systems require line-of-sight to ensure accurate missile guidance commands (12:84). Examples of semi-active SAM systems include the Soviet SA-6 and SA-11, or the American Hawk. The Soviet SA-8 is an example of a command-guided missile system. Passive SAM systems, such as the infrared heat-seeking SA-9 and SA-13, are not modeled, nor are active guidance SAM systems, such as the SA-10, whose missile contains its own tracking/guidance radar (25:111-112). Passive or active SAM systems do not require the ground radar to maintain line-of-sight with the target during missile time-of-flight, because their missiles home on the target without input from the ground radar.

Assumptions. To focus on the role of terrain in aircraft and SAM system encounters, the following assumptions were used:

1. The aircraft maintains a straight flight path throughout the encounter with the SAM site. Defensive maneuvers, defense suppression, and electronic counter-measures were not modeled.

2. The lethal range of the SAM system is circularly symmetrical. In reality, minor variations would occur due to changes in target radar cross-section and characteristics of a specific SAM system.

3. When the target becomes unmasked by terrain, the SAM's tracking radar reacquires the target after a constant time delay. This time delay was used as one of the factors in the Analysis of Variance and in the Multiple Regression equation, and is used to account for (1) time spent reacquiring the target, and (2) the minimum tracking time the SAM system requires before launching a missile, which would be dependent on system capability and launch doctrine.

4. The SAM system uses proportional navigation (a constant bearing intercept course or "lead") to guide the missile to the target. This assumption is valid for nearly all Soviet SAM systems of interest (25:112).

General Approach

Choice of Terrain. Two contrasting types of terrain were chosen for analysis: (1) the "Fulda Gap" area around Fulda, West Germany, an area of moderately rugged terrain with elevations up to 3100 feet, and (2) the North German Plain near Hamburg, an extremely flat area where hills are rare and do not exceed 600 feet in elevation. Both of these areas are expected to be major avenues of attack if the Warsaw Pact should invade West Germany.

Terrain Data Source. Digitized terrain elevation data, developed by the Defense Mapping Agency, serves as raw data for this project. Aeronautical Systems Division, Engineering System Survivability and Effectiveness Branch (ASD/ENSSE) at Wright-Patterson AFB has computer software which will access this terrain data (22). Four stages of data

processing were required to translate this terrain data into a suitable form for this research:

Stage 1. Select 20 suitable SAM locations in each of the two terrain types. Use the ASD/ENSSE computer software, with minor modifications, to determine line-of-sight conditions around each SAM site out to 30 nautical miles. Six different altitudes were used.

Stage 2. For each SAM site's coverage area, determine the distances in which an aircraft following a straight-line flight path would be masked or unmasked with respect to the SAM system tracking/guidance radar. Record these distance segments by start point, length, and type (masked or unmasked).

Stage 3. Group these distance segments into 49 cells of relatively homogeneous data (as shown in Figure 1). This grouping must be accomplished for each of the six aircraft altitudes of interest, and for each of the two terrain types, flat and hilly.

Stage 4. Fit theoretical probability distribution functions to the distance segment values in each of these cells, using "AID" statistical software by Pritsker and Associates, Inc.

Simulation. Once the data base was in the form of probability distributions, a combined SLAM network/discrete event simulation model was used to determine the ultimate measure of merit, Number of Completed Missile Engagements per Nautical Mile Flown within the SAM's Lethal Envelope ("Engagements per Nautical Mile"). Simulations were run on both terrain types, using variations on five factors: aircraft airspeed, aircraft altitude, average missile velocity, SAM system response time, and threat density.

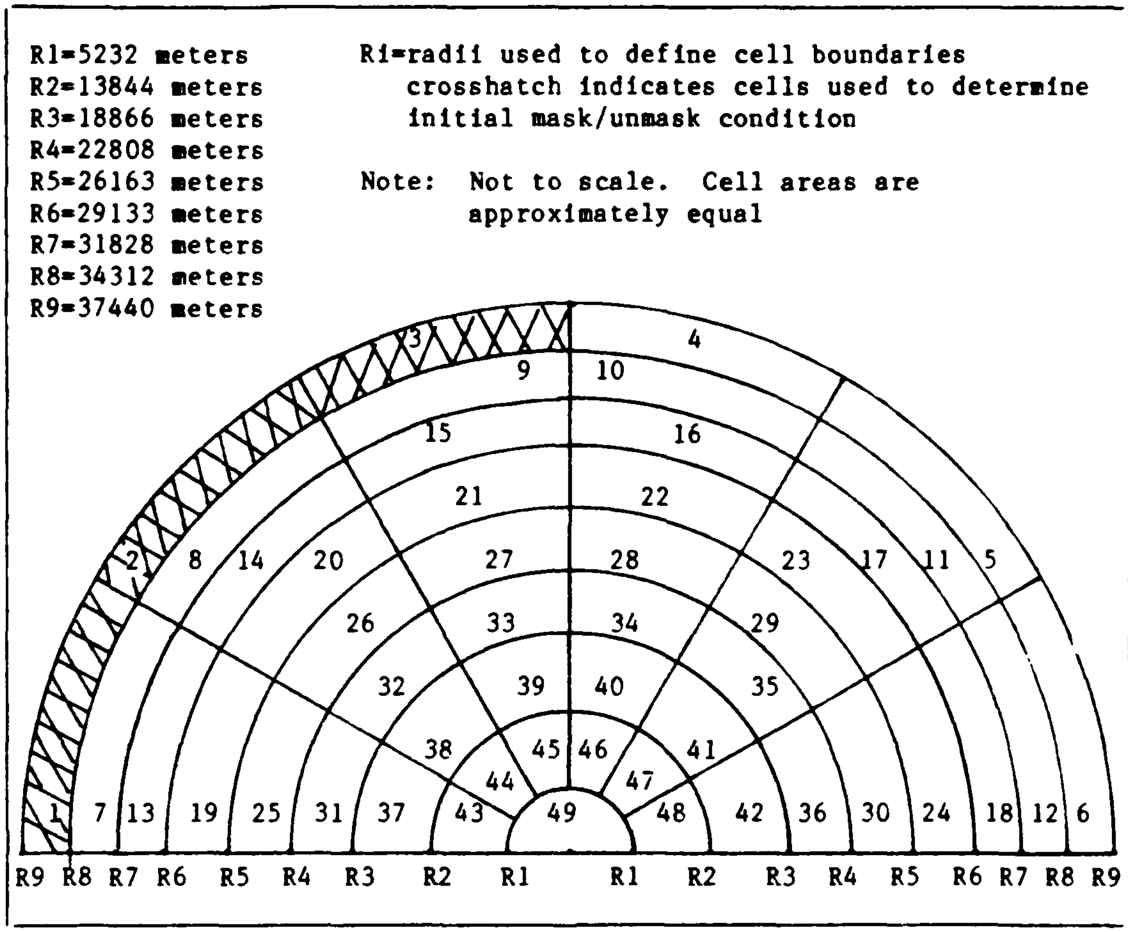


Figure 1. SAM System's 49 Cells for Grouping Masked/Unmasked Distance Distributions

Output Analysis. The simulation results were analyzed using a full factorial designs and multiple regression from BMD Biomedical Computer Programs (BMDP) software. Factorial design analysis was used primarily to gain insight into the interactions of the five factors. The multiple regression equations (one for each terrain type) represent the end-product of this research. Inputting values for aircraft altitude and airspeed, average missile velocity, SAM system response time, and threat density, into these regression equations will produce a predicted value for Engagements per Nautical Mile in that terrain type. This measure can then be the "terrain effects" input into a larger parent model.

Sequence of Presentation

In the next chapter, a review of related literature will be conducted, including an examination of other efforts to model terrain effects on aircraft·encounters with SAM systems. In Chapter Three, the basic geometric relationships and definitions that were used to quantify terrain attributes will be introduced. In addition, the various models that were employed will be examined, including the simulation model that produced the measure of merit, Number of Engagements per Aircraft per Nautical Mile. Several stages of data transformation were required for this research, and Chapter Four will discuss these stages in detail. Chapter Five examines the factorial design and multiple regression analyses that were conducted on the results of the terrain-effects simulation model. The impact of each of the five factors studied, and their interactions, will be investigated, and conclusions will be drawn based on the overall findings. The ultimate product of this research, the regression equations that predict terrain effects per terrain type, will be derived and presented. Finally, in Chapter Six, the research effort will be summarized, and recommendations for any follow-on study will be made.

II. Review of Related Literature

Definitions

In order to discuss terrain effects on a SAM system's ground radar, one must deal with four terms: Radar Horizon, Mask Angle, Elevation Angle, and Multipath Angle.

Radar Horizon. The atmosphere causes diffraction of electromagnetic signals, allowing radar to detect targets beyond the optical horizon. The upper bound on this detection range is termed the radar horizon (12:43), and any valid terrain model must account for it. A simple formula for calculating radar horizon is:

$$R = 4117.3\sqrt{h}$$

where h is the target altitude and R is the radar horizon, both in meters (1:17).

Mask Angle and Elevation Angle. To illuminate a target, a radar must work with two angles, elevation angle and mask angle (see Figure 2). Elevation angle is the angle between the horizontal plane of the radar and a straight line between the radar and the target. Mask angle is the lowest angle at which the radar has a clear line-of-sight over terrain or other obstructions. Mask angle often changes for each degree of azimuth and for each distance from the SAM site considered. The SAM site can only detect the target when the elevation angle is greater than the mask angle at the target's location. Terrain has been difficult to model because of the random nature of the mask angles around any particular SAM site.

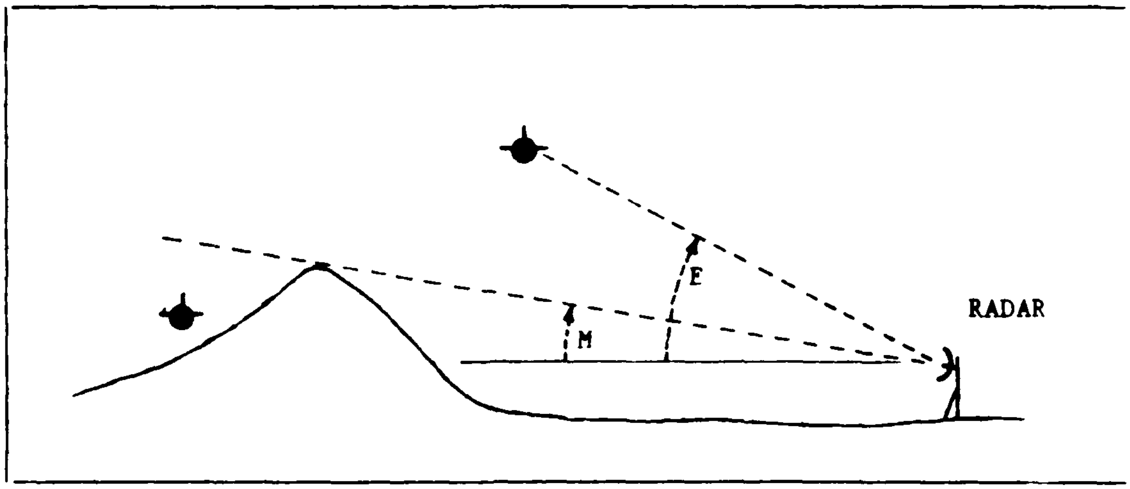


Figure 2. Elevation Angle (E) and Masking Angle (M).

Multipath Angle. Multipath angle occurs when the elevation angle from the SAM's ground radar to the target is less than approximately 0.25 degrees above the horizon, depending on the SAM system. When that elevation angle occurs, the aircraft's radar return reflects off the surface of the earth. This reflected signal interferes with the actual radar return from the target, and prevents the radar from determining the range of the aircraft (1:41). The result is that the radar cannot pinpoint the location of the target well enough to launch a missile. If the elevation angle increases above this critical value, the SAM system's tracking radar can lock onto the target.

Previous Terrain Modeling Attempts

Five recent Masters theses have dealt with the aircraft-SAM encounter. Two of these theses, by Foley and Gress (11:31-32) and Anderson and Nenner (1:41-42), consider terrain only to a limited extent. Two other theses, by Leek and Schmitt (16:43-44) and Neal and Kizer (20:50), achieve more terrain detail by using a U.S. Navy line-of-sight model. The fifth thesis, by Commander McKinney of the Naval Postgraduate

School, models terrain masking around specific radar sites, but does not attempt to generalize the results to represent entire terrain types. McKinney does not model the aircraft-SAM engagement (17:12).

Anderson and Nenner. Anderson and Nenner use radar horizon and multipath angle computations to determine the initial line-of-sight limitations a SAM site would experience (1:17-18). However, they assume a level horizon. They do not consider terrain variations or the opportunity for an aircraft to remask behind terrain. Foley and Gress handled terrain in the same manner (11:31-32).

Leek and Schmitt. Leek and Schmitt used a terrain model of "Rolling Farmland with Close Forests" in their thesis. They obtained their data from the Line-of-Sight Handbook, published by the Naval Weapons Center (4). Specifically, they used mathematical equations to approximate the curves of the graph shown in Figure 3 (16:43-44). They then used this model only once during each aircraft-SAM encounter to determine if the SAM had a clear line-of-sight to the target when it first came into missile range. Leek and Schmitt noted that their model "does not allow for the case in which an aircraft alternately passes behind terrain features and then comes back into the radar's view as time progresses" (16:85-86). They did use multipath angle calculations (16:13-14), but were able to omit radar horizon computations because the electronic countermeasures they modeled prevented radar detection until well inside the radar horizon. Neal and Kizer, in their thesis, used the same terrain model that Leek and Schmitt had derived (20:50), but recommended that terrain be modeled in more detail (20:122).

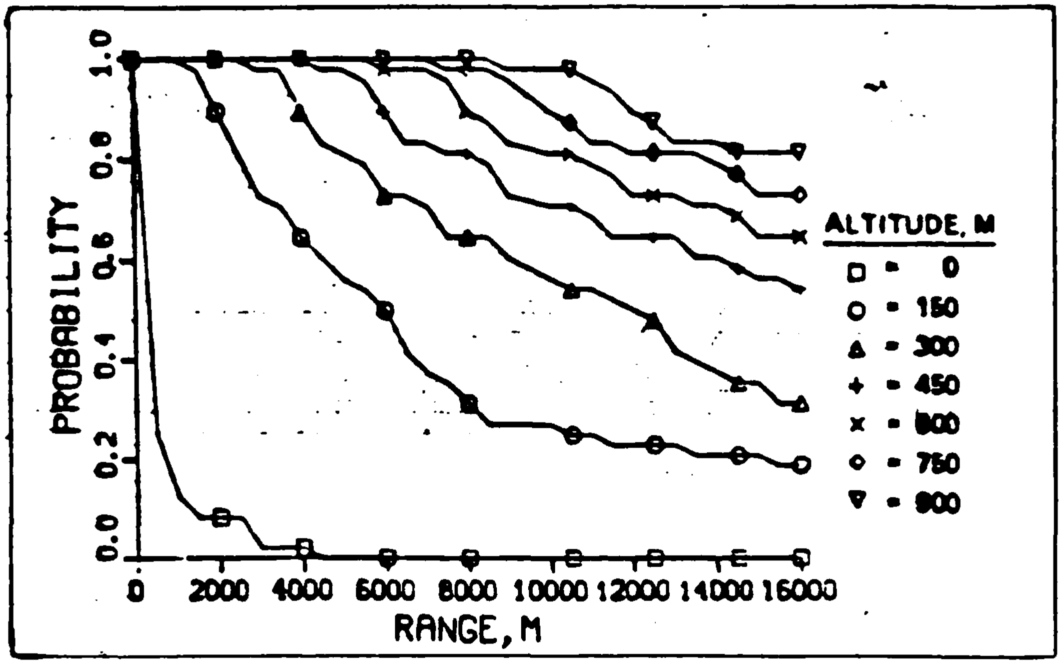


Figure 3. Average Probability of Line-of-Sight in Rolling Farmland With Close Forests as a Function of Range.

There are difficulties with the Navy Line-of-Sight Handbook, however, that make it less than ideal for use in a terrain model for SAM-aircraft encounters. First, it should be noted that the purpose of the Line-of-Sight Handbook is to enable a Naval aviator to determine the altitude he must fly to be able to have a clear line-of-sight to a ground target (4:3). Although the Line-of-Sight Handbook does not specify target elevations, many of these ground targets are probably located at lower terrain elevations (see Figure 4). In contrast, SAM sites will purposely be located to have line-of-sight coverage of the anticipated air approaches into a battle area. Therefore, in most instances, SAM sites will be located at the highest elevations practicable. The difference between line-of-sights from these opposing elevations will be substantial in rougher terrain.

Secondly, the data for the Line-of-Sight Handbook was collected from an average of five sites per terrain type, using standard surveying

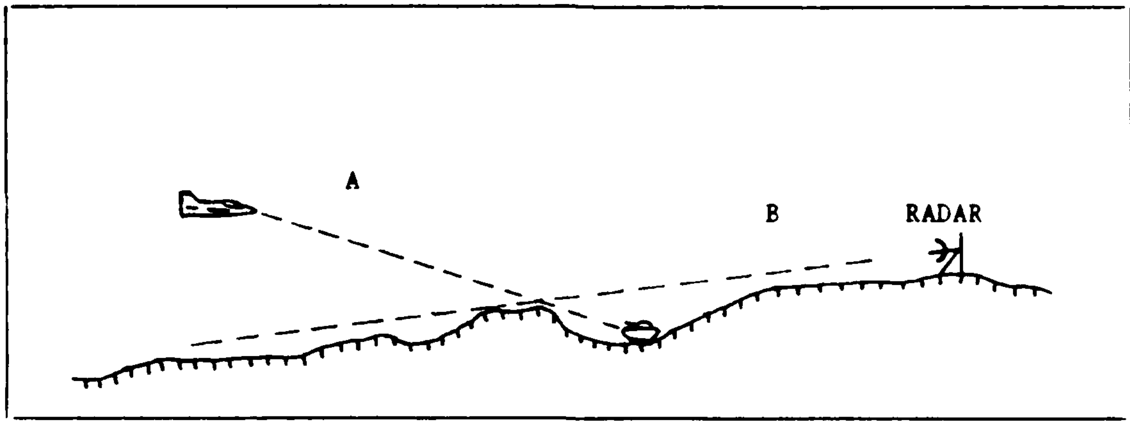


Figure 4. Line-of-Sight Measured for Line-of-Sight Handbook (A) and Desired SAM Line-of-Sight (B).

equipment (4:6). Approximately 100 line-of-sight measurements were taken for each terrain type (4:58). Two points need to be made about this data collection method: (1) Surveying equipment is much shorter than the average SAM radar antenna height, and (2) the data base would be improved if more sites were checked and more observations were taken per site. In summary, the Line-of-Sight Handbook offers only a very rough approximation of terrain effects on aircraft-SAM encounters.

McKinney. Unlike the other four theses, which all focus on the ability of an aircraft to survive an encounter with a SAM system, McKinney's thesis concentrates on determining where terrain will mask aircraft from a given SAM site. The objective of his thesis is to find any areas of inadequate enemy radar coverage that could be exploited by friendly forces (17:12). For his raw terrain data, McKinney used the world-wide Digital Terrain Elevation Data (DTED) base developed by the Defense Mapping Agency Aerospace Center (17:11). From there, he developed software to determine where terrain masking occurs around a specific SAM site, given inputs of SAM site location and target aircraft elevation. McKinney's computer program produces map displays of where

aircraft flying at the specified altitude would be masked or unmasked (17:29).

McKinney's thesis effort appears to be a valid foundation for the authors' research on generalizing terrain factors in the aircraft-SAM encounter. It was not used because the Engineering System Survivability and Effectiveness Branch of Aeronautical Systems Division (ASD/ENSSE) at Wright-Patterson AFB offered a better alternative. ASD/ENSSE has equivalent computer software, the same DTED data base, and considerable experience in using both. ASD/ENSSE has also validated the software, and were able to make computer resources available for this research (22).

Selecting Methodologies

Objectives. The objectives of this research effort are to (1) model types of terrain, (2) model the impact of terrain on the aircraft-SAM system encounter, and (3) explain that impact. As R. D. Specht points out, the model one chooses should depend not only on what is being modeled, but also on the questions to be asked of the model (24:212).

Alternative Solutions. It was hypothesized that several variables would be involved in these models. For instance, to model the impact of terrain on the encounter between aircraft and SAM systems, at least six variables would be involved: Aircraft altitude, aircraft airspeed, missile speed, threat density, SAM system response time, and how close the aircraft passes to the SAM site (Radius of Closest Approach). Given the number and nature of these variables, two methods could be used to make the desired measurements, using either on-site data collection or computer models.

On-site Data Collection. If resources were available, actual experimentation of the tyoe used to produce the Naval Weapon Center's

Line-of-Sight Handbook could produce the desired measurements. An iterative approach could be employed to explore each of the factors listed above, using a SAM radar system and an actual aircraft. Two important advantages would be accrued by this method: (1) the validity of the data would be irrefutable, and (2) the impact of cultural factors, vegetation, and seasonal changes in vegetation could be captured. On the other hand, actual on-site data collection would also have serious drawbacks: (1) data collection in some nations would not be feasible, so the derived model might not apply to some areas of interest, (2) adequate data base buildup would be a relatively long process, especially since a digital terrain data base is already in place, (3) some factors, such as aircraft altitude and airspeed, may be difficult to control precisely, and (4) considerable expense would be incurred. Given the scope of this study, computer models were a better alternative.

Computer Models. Specht notes that while computers can be used in analytical models, their use is absolutely required for problems in which "the relevant factors are too numerous or their interrelations too complex to be handled analytically" (24:224). Norman C. Dalkey uses similar logic to justify computer simulation of a problem: "The principle reason for resorting to simulation ... is that the phenomena to be studied are far too complex to be manageable in any other way" (5:246). This description certainly is applicable to modeling terrain effects on the aircraft-SAM encounter, given the number and type of factors involved. It is worth noting that the first four Masters theses discussed previously all relied on computer simulation to model terrain effects on the aircraft-SAM encounter. The fifth thesis did not attempt to model this encounter, and therefore did not need to use simulation.

For these reasons, a computer model was developed to accomplish the

first objective of this research, to model types of terrain, and computer simulation was used to model the impact of terrain on the aircraft-SAM system encounter. The third objective, to explain terrain effects on the aircraft-SAM system encounter, was achieved through combinations of factorial design analysis of variance (ANOVA) and multiple regression.

Conclusion

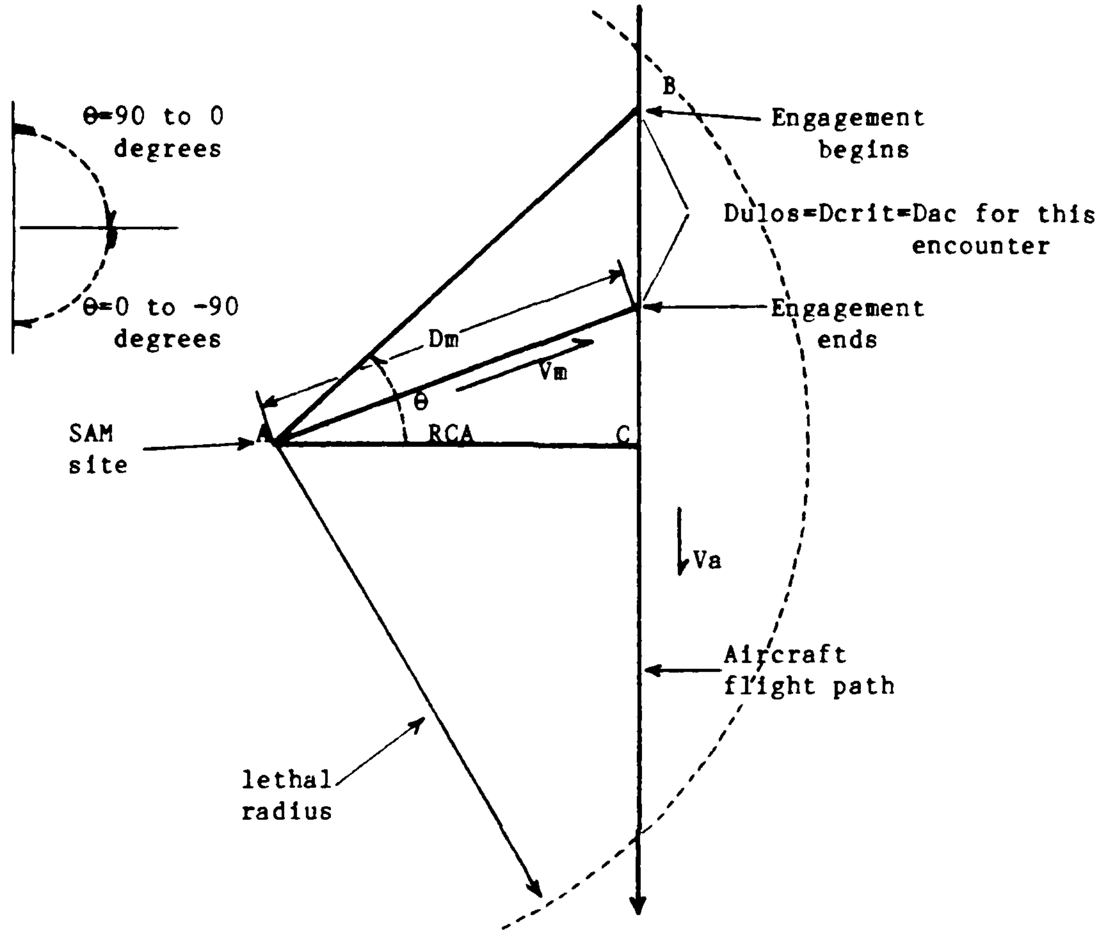
In recognition of the limitations of current models with respect to terrain effects, HQ USAF Studies and Analysis Directorate for Theater Force Analyses, Fighter Division (AF/SAGF), has requested assistance in developing a method to account for terrain effects in existing models (18). Previous limitations in obtaining realistic data have recently been overcome with the development of Digitized Terrain Elevation Data (DTED). Using computer modeling methodologies, DTED data, and software developed by ASD/ENSSF and the authors, terrain effects on the engagement between aircraft and surface-to-air missile systems can be accurately modeled.

III. Model Formulation

The primary focus of this research concerned terrain influences on aircraft and SAM system encounters. With real-world experimentation not feasible, the research was conducted with a series of computer models.

An aircraft/SAM system encounter is a complex and dynamic process involving many variables. For example, aircraft flight parameters, missile guidance and flight parameters, and threat system battle area density and operational parameters are all factors that influence these encounters. In fact, the influence of any one of these factors can not be realistically evaluated without consideration of the others. Therefore, relatively simplistic models were used for (in the authors' opinions) factors that had to be considered before the effect of terrain on aircraft/SAM system encounters could be determined.

The data generation model development process involved three overlapping stages. First, the "relatively simplistic" models of what the authors call "supporting factors" were developed. Second, a detailed model of relevant terrain attributes was developed. Third, a simulation model of aircraft/SAM system encounters (which used the two previously described models) was developed. Data for follow-on analysis was generated with this simulation model. Figure 4 summarizes the basic geometric relationships and definitions that were used throughout the modeling process. Figure 5 is an overall depiction of the scenario used in the simulation model.



Dac=Distance airplane travels during missile time-of-flight

Dm=Distance a missile travels between launch and intercept points

Dmlos=Distance the aircraft travels while masked by terrain

Dulos=Distance the aircraft travels while not masked by terrain

Dcrit=The Dulos required for a missile to complete an intercept

RCA=Radius of Closest Approach between the aircraft and
the SAM site

θ=Angle between RCA and line AB

Vm=Missile velocity

Va=Aircraft velocity

Figure 4. Encounter Geometry and Term Definition

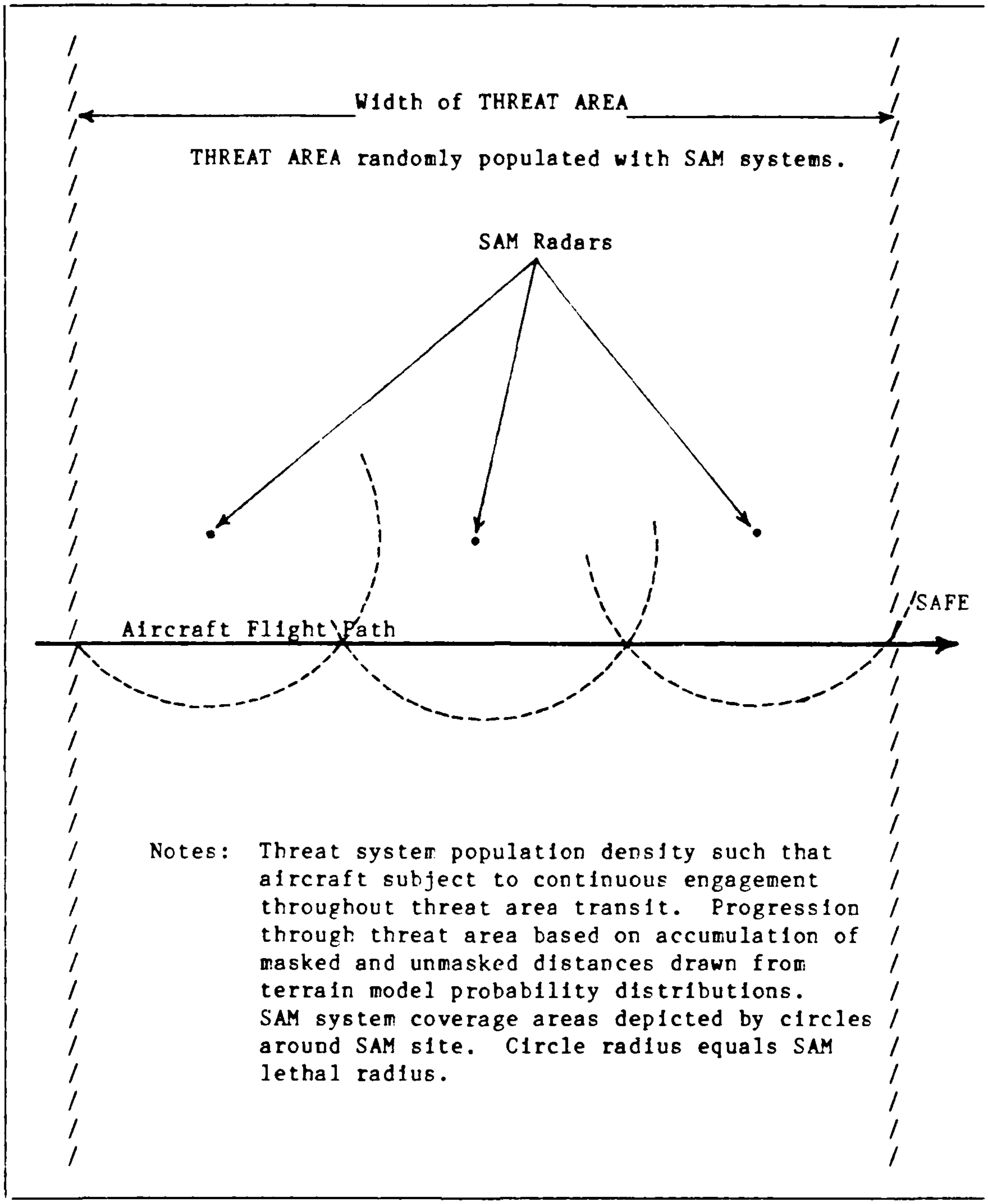


Figure 5. Simulation Model Scenario

Assumptions

Not all factors relevant to real-world aircraft/SAM system encounters were modeled. Some were dealt with by the following assumptions:

1. The aircraft maintains a straight line flight path throughout the encounter with the SAM system. Defensive tactics, defense suppression, and electronic counter-measures were not modeled.

2. The lethal range of the SAM system is circularly symmetrical. In reality, variations will occur due to changes in target radar cross-section and the operational characteristics of a specific SAM system.

3. The SAM system tracking radar can reacquire the target at all times after terrain masking by the target. This is an optimistic assumption from the SAM system standpoint, since tracking radars have relatively poor search capabilities due to the narrow beam widths, and therefore can search far less airspace than search radars (4).

4. Momentary masking by the aircraft during an engagement will in all cases (regardless of the shortness of masking duration) defeat a missile during intercept. (Changes of line-of-sight condition (from unmasked to masked, for example) were evaluated only at points on 360 discrete radials originating at the SAM site.) In reality, very short loss of radar return will not necessarily cause a tracking radar to break lock. The time without a radar return required to break lock depends on radar system tolerances.

5. The SAM system uses proportional navigation. This assumption is valid for nearly all Soviet SAM systems of interest (25:112).

6. SAM systems are restricted to those systems for which missile guidance is dependent on ground tracking and/or illuminator radars.

Supporting Factors Modeling

Aircraft flight parameters and SAM system operational parameters were the aircraft and SAM system factors for which simple models were used. In all cases, these factors were modeled by selecting discrete

values from an operational range of interest. Three or more values for each factor were used in anticipation of follow-on sensitivity analysis. Also, since they were required anyway for the terrain study and are of interest in aircraft/SAM encounters, the relatively simple task of including various factor levels would result in a final model that would better represent real world conditions than if single values for each parameter had been used. These supporting factor models were implemented in the main simulation model simply by specifying discrete values for subsequent use in the discrete event FORTRAN coding. In the case of the missile guidance algorithm, a mathematical expression which determines the lead angle required for missile intercept (given the starting geometry, aircraft airspeed, and missile speed) was used.

Aircraft Flight Parameters. Altitudes of 50, 100, 250, 500, 750, and 1000 feet above ground level (AGL), and airspeeds of 6, 7, 8, and 9 nautical miles per minute were used. These include generally accepted values that may be anticipated for a variety of aircraft during typical low level penetration profiles and transitions through battle areas.

SAM System Parameters. Missile speeds and SAM system delays were varied during experimentation. To avoid a potentially technical model (which could of itself require an extensive research effort), the missile flyout problem was modeled using simplifications of guidance algorithms and velocity profiles. Proportional navigation was modeled with a constant bearing intercept course (which is the idealized version of the proportional navigation algorithm)(3:2-167), and missile velocity profiles were restricted to single values, with no provision for the velocity profiles that would occur during boost phase, sustainer operation, or glide. Missile speed values were computed by taking the maximum speed attained by a representative sample of Soviet SAMs,

assuming a supersonic missile (Mach=1) at intercept, and taking the average of these two speeds. Unlike the aircraft flight parameters, the values for missile speeds are more qualitative in nature, representing low, medium, and high relative settings for this factor.

SAM System Delays. Delays for command and control, operator proficiency, equipment limitations, etc. were modeled by assuming an all encompassing delay between the time an aircraft is exposed to the SAM system tracking radar and missile launch.

Battle Area Density of Threat SAM Systems. The number of threat systems present in the battle area was simulated by specifying the maximum Radius of Closest Approach (RCA, see Figure 4) at which an aircraft could pass a SAM site. Higher threat densities were simulated during experimentation by specifying smaller maximum allowable RCAs. From the perspective of the aircraft pilot, this restriction of RCA translates into the knowledge that at no time while transiting a threat zone will he be on a route such that he will pass further than the maximum specified RCA from enemy SAM systems. Figure 6 shows the relative effect of varying the maximum allowable RCA to simulate threat density. In the low threat density scenario, the aircraft still has a chance of passing within close range of the SAM site. However, over many random selections of RCA during the simulation runs, the mean of the RCAs selected for the low threat scenario will be larger than that of the high threat scenario. Therefore, more relatively long range encounters will occur with the low threat density scenario. In general, random positioning of threats within a threat area of varying firing battery concentrations can be simulated with this technique.

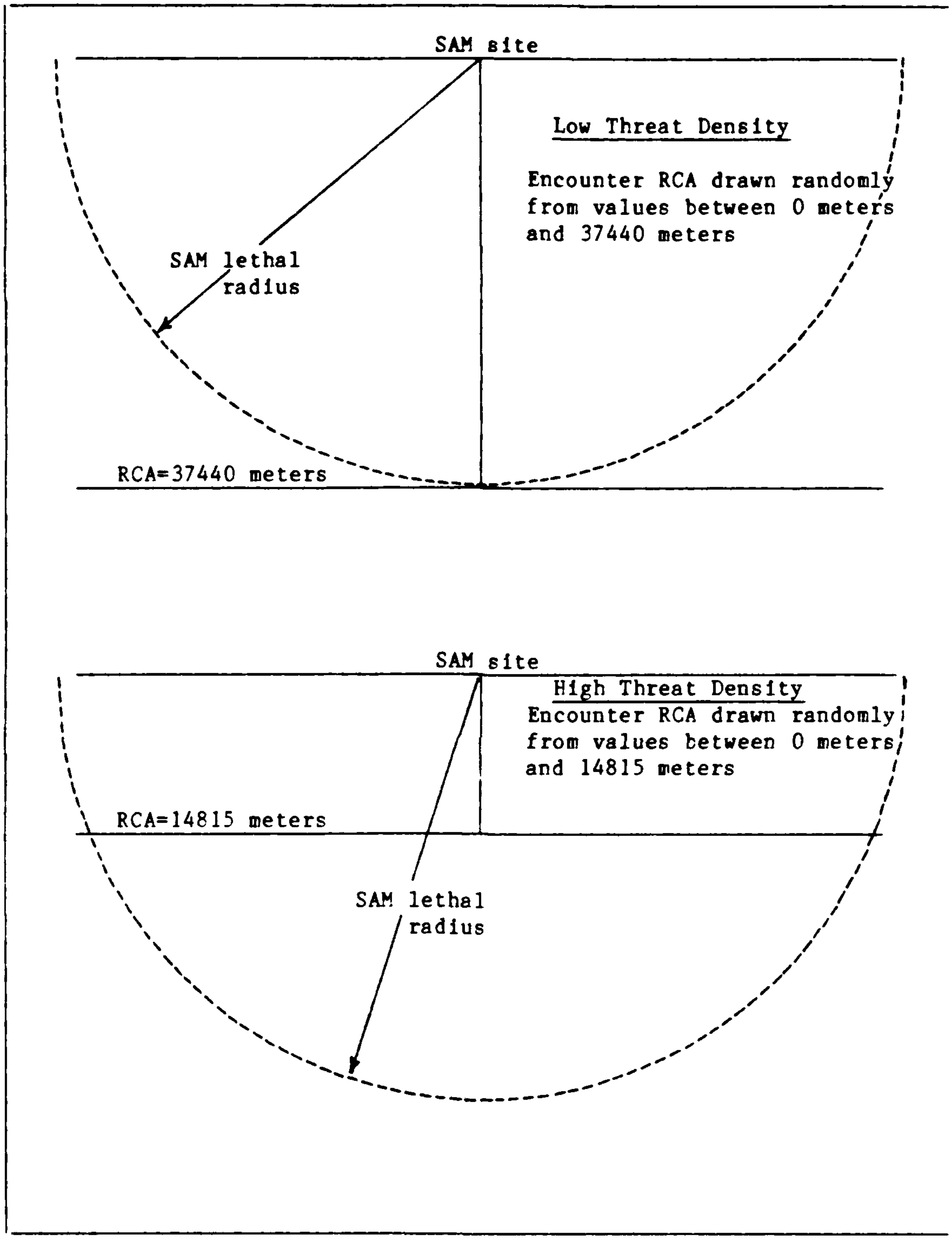


Figure 6. Threat Density

Terrain Model

The terrain model for this research was developed from Defense Mapping Agency digital terrain data. Its derivation will be discussed in Chapter 4. As shown in Figure 1, it consists of a set of 49 probability distributions for each aircraft altitude of interest for both of masked and unmasked distances relative to a SAM ground radar. Each probability distribution is derived from the frequency distribution of distance measurements originating in the data cells defined by the angle and range convention shown in Figure 1. Basically, each cell of the model has associated with it a characteristic frequency distribution of masked and unmasked distances. By specifying a range and angle relative to the SAM site, a sample from the appropriate probability distribution may be taken to produce a representative masked or unmasked distance that an airplane could be expected to encounter if it were located in that cell at some point during its transit of the SAM system coverage area.

This terrain model was developed for use in a simulation model. The frequency distributions of masked and unmasked distances were therefore approximated by theoretical distributions in order to use SLAM simulation language random variable generation capabilities. Direct sampling from the empirical frequency distributions during simulation (instead of from the corresponding theoretical approximations) was not attempted.

The terrain model for the Fulda area of West Germany included aircraft altitudes of 50, 100, 250, 500, 750, and 1000 feet AGL. The altitudes in the North German Plain model were 50, 100, and 250 feet AGL. There was not enough data to construct an adequate Plain model for altitudes above 250 feet AGL. This is due to the very flat terrain in the North German Plain. Data generation techniques (discussed in Chapter 4) were unable to identify masked and unmasked distance start points

above 250 feet AGL within a 20 nautical mile radius, because, in general, unmasked distances started beyond 20 nautical miles and did not end throughout the aircraft transition through the threat zone.

Simulation Model

The simulation model was used to generate data for the follow-on analysis. Conceptually, it simulated the roles that actual SAM systems and aircraft would perform during restricted (in accordance with the preceding assumptions) real-world encounters. Structurally, it is a SLAM simulation language combined network/discrete event simulation model. The SLAM network is designed primarily to test for data collection triggers that are set in the discrete event subroutines and collect data values as appropriate. Figure 7 is a summary of the logic followed in the simulation model. In Figure 7, the "threat area" includes the overall battle area within which an aircraft could encounter a SAM system. A "SAM system coverage area" is that part of the threat area within the lethal radius (as shown in Figure 4) of a single SAM system.

SLAM Network. The SLAM Network is shown in Appendix A. Important Control and Network Statements are:

Control Statements. Simulation time is in increments of minutes, and each replication represents 16.65 hours ("INIT,0,999"). This time corresponds to fifty simulation runs per replication. Conceptually, the aircraft entity makes fifty passes through the threat area per replication. Seed values are set to permit multiple, independent runs/ replications. The values of the independent variables (missile airspeed, aircraft airspeed and altitude, threat system operational delay, and threat density) are reset for each simulation run by the INTLC statements.

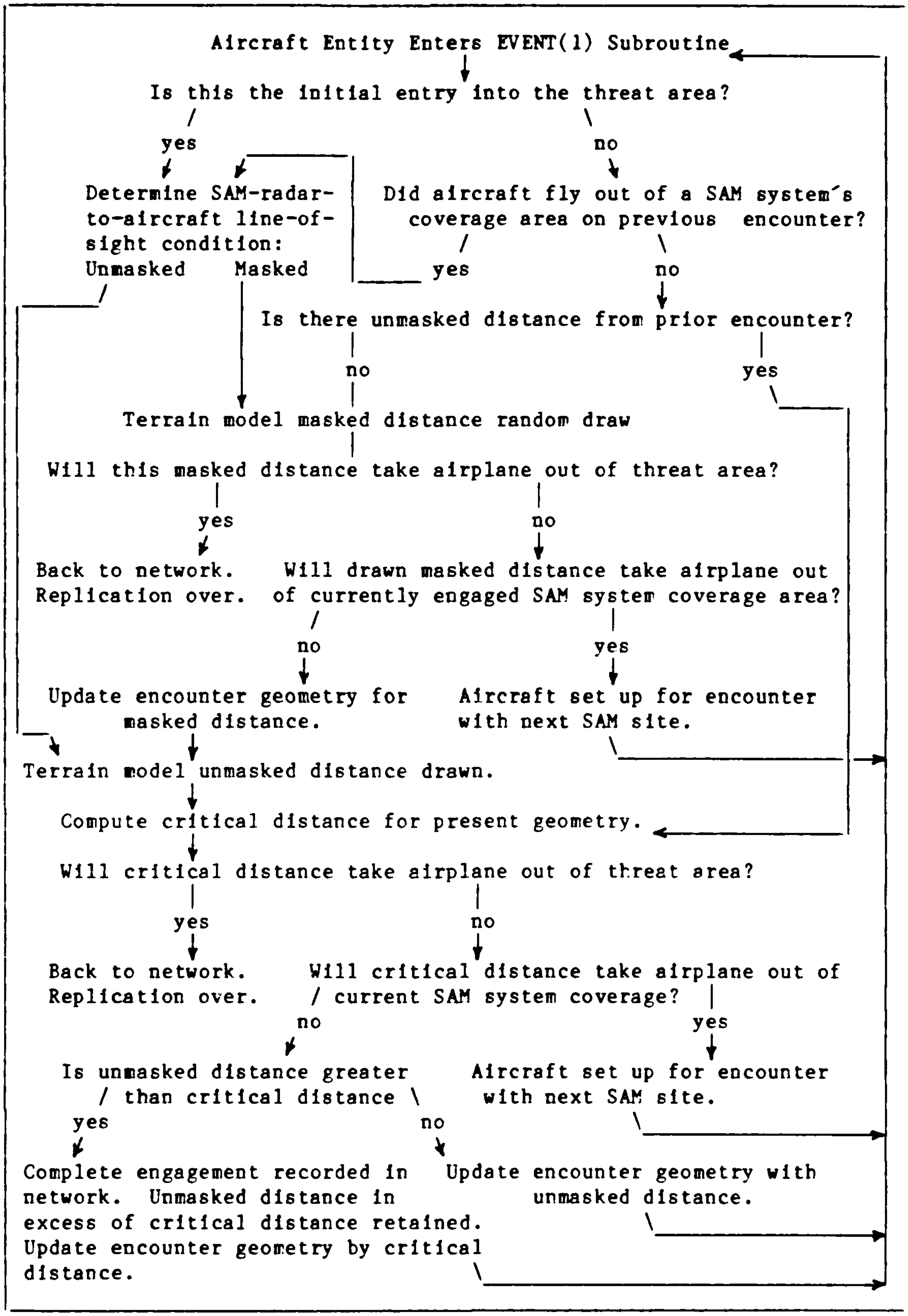


Figure 7. Simulation Model Flow Chart

The values used for the independent variables are summarized in Table I. Simulations for the Fulda area were done first.

Table I. Independent Variable Experimentation Values

Variable	Fulda	Plains
Aircraft Altitude (feet AGL)	50	50
	100	100
	250	250
	500	
	750	
	1000	
Aircraft Airspeed (nautical miles per minute)	6	6
	7	7
	8	8
	9	9
Maximum Allowable RCA (meters)	14815	14815
	25926	25926
	37440	37440
Missile Speed (nautical miles per minute)	19.0	19.0
	22.3	22.3
	25.0	25.0
SAM System Delays (minutes)	0	.01667
	.08333	.10000
	.16667	.18333
		.26667

Network Description/Statements. An entity simulating an aircraft is created every 20 minutes of simulation time and assigned attributes of airspeed, altitude, and a numerical trace value. The overall flight distance through the simulated battle area is such that 20 minutes between entity creations will always ensure adequate time separation between entities. Only one aircraft is in the network at a time. The simulated aircraft entity (hereafter refered to simply as the aircraft) immediately enters the main discrete event subroutine (EVENT(1)) in which the actual aircraft/SAM system encounter is modeled. When the aircraft returns from EVENT(1) to the SLAM network it is routed to appropriate network nodes depending on what happened in EVENT(1).

Global variables set in EVENT(1) dictate the subsequent network routing.

If the aircraft survived the encounter but is still within the coverage of the same SAM system, it is routed back to the EVENT(1) subroutine for another encounter. If the aircraft did not survive the encounter, it is routed to a data collection section of the code (beginning at the DIE node) where the number of completed encounters is accumulated and the distance within the threat area at which the completed encounter occurred is recorded. Conceptually, the aircraft is then regenerated and returns to the EVENT(1) subroutine for continued processing, as if a wingman is now being engaged.

If, during processing in the EVENT(1) subroutine, the aircraft flys out of the SAM system area of coverage, it is automatically assumed to have survived any engagement that was in progress. If global accumulator variables in EVENT(1) also indicate that the aircraft has transited a distance greater than or equal to the prescribed width of the threat area, the simulation run is over and the aircraft is routed to the END node. If, however, the threat area has not been crossed, the aircraft is routed back to EVENT(1) (node R1) and immediately engaged by a new SAM system as it passes out of the coverage area of the previously engaged SAM. The aircraft is exposed to continuous coverage by threat SAM systems.

<u>TEST2.FOR FORTRAN Program</u>. TEST2.FOR is shown in Appendix B. It contains one EVENT subroutine, three USERF subroutines to perform simple calculations, and an OTPUT subroutine.

<u>EVENT(1)</u>. EVENT(1) is the main discrete-event subroutine for this project. It manipulates all of the time persistent variables tracked in the SLAM network. Each time EVENT(1) is entered from the network, the global variable XX(7) is tested to see if the aircraft has

transitioned between separate SAM sites. If it has transitioned, or if the aircraft is making its initial entry into the threat area, the aircraft-to-SAM geometry is established for the new engagement with a random draw to determine the engagement RCA. If the aircraft is just entering a SAM ring, USERF(3) is used to determine whether the aircraft is initially masked or unmasked. After this initial determination of the masked/unmasked condition (and the resulting iteration), subsequent iterations of the subroutine will start with a masked flight distance condition. If the aircraft has not transitioned between SAM sites, global variables accumulated prior to the preceding exit to the SLAM network are the start-up values when the entity returns to EVENT(1). Since the unmasked distance is of primary interest, a masked distance is computed, encounter geometry is updated with this masked distance, an unmasked distance is computed, the outcome of the unmasked portion of the encounter is determined, and variables are reset to retain the appropriate geometry while manipulations are made in the SLAM network. Every time an aircraft flies an unmasked distance, a computation is made to see if the time during which the aircraft was exposed was sufficient for a SAM intercept (SAM proportional navigation assumed). If the missile can intercept the target before the target remasks, EVENT(1) signals the SLAM network that a completed engagement has occurred (XX(3)=0). In the next EVENT(1) iteration, the regenerated aircraft will finish flying any remaining unmasked distance not completed during the previous completed encounter.

USERF(1). USERF(1) computes the time-of-flight during which an aircraft is unmasked. This time-of-flight will be compared to the missile time-of-flight required to intercept the aircraft during the unmasked distance of concern, and therefore determine if a complete engagement can occur.

USERF(2). USERF(2) computes aircraft time-of-flight through an area of SAM system coverage. This time advances the simulation time as the aircraft progresses through the SAM threat area.

USERF(3). USERF(3) determines initial SAM line-of-sight with the aircraft, based on the ratio of masked occurrences to the total masked and unmasked occurrences in the outer data cells around the SAM (see Figure 1). Each altitude setting has a specific ratio. A random draw is accomplished to see if the aircraft is initially masked or unmasked. If the aircraft is unmasked, radar tracking begins. This function is only called during the initial encounter between a given aircraft and the SAM. Subsequent encounters use alternating masked and unmasked distances. Two versions of USERF(3) were used for this study. One was for the Fulda area, and the other for the North German Plain.

OTPUT Sub-routine. OTPUT writes to a data file the altitude, aircraft airspeed, average total threat zone distance traveled by aircraft, a variable used only during model formulation/de-bugging (not used for follow-on analysis), number of fatal encounters, the specified maximum allowable rca, missile speed, and SAM system delay for each replication (50 simulation runs) of the model.

DISTANCES.FOR FORTRAN Coding. DISTANCES.FOR is a file containing two FORTRAN sub-routines which compute masked and unmasked distances based on which of 49 cells an aircraft is in. It is the terrain model discussed earlier. The derivation of these probability distributions will be discussed further in Chapter 4. An example discussing the DISTANCES.FOR coding techniques and summary of the distributions used in the terrain models are contained in Appendix C. The entire code listing was not included because of its length (approximately 6000 lines). However, the

coding structures are very repetitive, with only distribution parameter changes between structures. The subroutines contained in DISTANCES.FOR are called by TEST2.FOR. The terrain models were developed as separate FORTRAN code because of their length and the excessive compilation time required for minor changes to TEST2.FOR if DISTANCES.FOR was included as part of the TEST2.FOR code. Both TEST2.FOR and DISTANCES.FOR were easier to work with when separated. DISTANCES.FOR was the terrain model for the Fulda area, and DIST2.FOR was the terrain model for the North German Plain area.

Simulation Model Verification and Validation

Verification. The purpose of model verification is to ensure that the model is performing as intended (10). The verification process for this research centered on the simulation model used to generate data for use in development of the regression models. Verification of this model consisted of building/debugging the basic model through the use of SLAM traces and embedded FORTRAN "WRITE" commands, and checking output for computational accuracy and overall reasonableness.

Both the SLAM network and the major subroutine, EVENT(1), were built in stages. Simple input values were initially used to ensure that program branching and computations worked correctly. For instance, in building the SLAM network, a simplistic EVENT(1) was initially used which merely set "flag" values, allowing entities to cycle through only certain parts of the network. Thus the basic network structure could be verified quickly. The FORTRAN coding was designed initially to ensure that the desired conditional sequence of events would occur upon entry into the discrete event coding from the SLAM network. Logic errors were identified and corrected by checking output from debugging runs.

When the model was ready, preliminary computer runs were made to

check that output was reasonable. This phase identified several coding errors. A combination of SLAM "Trace" routines and "WRITE" statements imbedded in the FORTRAN coding was used to identify variables that were not being handled as intended, and the point in the code at which the errors were taking place. In most cases, abnormalities in output could be attributed to operations involving specific variables, and the appropriate suspect sections of code identified for investigation.

Identical random number streams were used for all debugging runs. After coding errors detected during initial debugging had been identified and corrected, further SLAM traces and imbedded "WRITE" statements were used to provide a running record of selected critical model variables, including random number stream values. This relatively exhaustive listing of model input and resultant output values was used to check for correct global variable value computation, retention, and re-initialization. Selected computer computations were verified by hand calculator to confirm that correct sections of code had been accessed for appropriate input values. For example, it was confirmed that, given a relative position between a simulated SAM site and aircraft, the appropriate line of the terrain model computer code was being accessed to produce a value of masked or unmasked distance for further model processing. Variables involved in computations with a potential of "blowing up" (division by zero, square root of a negative number, etc.) were tracked very closely to ensure that they were correct.

The result of these verification steps is output that is reasonable and logical. Although a systematic test of every line of the terrain model would be difficult (mainly because selection of a specific line of code depends on a series of conditional random number draws), the overall model has run for over 15 minutes of CPU time on several occasions with

no abnormalities noted.

Validation. The question of interest in the "Validation" phase is whether the model accurately represents the real world system (2:377). Since real-world terrain masking effects data is not available, ensuring high model face validity and assumption accuracy must be relied upon (18).

Face Validity. The authors have over 2,500 hours of experience in flying tactical fighters, much of it relying on terrain masking tactics, and believe that the basic model has high face validity. The data produced by the model showed the tendencies that were anticipated. For example, as aircraft altitude increased (while all other factors were held constant), so did the number of successful engagements. Follow-on data analysis (presented later) was also intuitively appealing.

It must be emphasized that strict, rigorous, and formal validation of this model is not possible. Such validation would first require comparisons to real world data derived through experimentation under combat conditions in Central Europe. This is clearly not feasible. Even the conceptual approach to terrain modeling can not be comparatively validated, since there are no other known terrain-masking models of this type with which to compare (10).

IV. Discussion of Data

Introduction

This chapter will review the transformations that were made to the original terrain data base to derive the final data used to generate the measure of merit, Number of Engagements per Aircraft per Nautical Mile. Four layers of data transformation were required, resulting in 49-cell groupings that accurately model entire types of terrain. Care was taken to keep the data as close to its original character as possible. The result is a terrain model that should be usable by a wide variety of parent models.

Original Data Base

The original data base for the terrain model is Digital Terrain Elevation Data (DTED) produced by the Defense Mapping Agency Aerospace Center (DMAAC). The objective of the DTED program is to digitally map the entire surface of the earth (6). DTED has already been used in many major projects, such as the cruise missile program (22) and the U.S. Army's Firefinder program, a project designed to precisely locate enemy artillery (8:v). DTED is unclassified, and is available on a subscription basis to a number of DOD users (6:vi).

The geographic location of terrain in DTED is referenced in the World Geodetic System, and terrain elevation values are in Mean Sea Level. Each DTED file contains the elevation data for a one-degree square of the earth's surface, and all data in the file is relative to the latitude and longitude coordinates of the southwest corner of that degree square. Within the file, data is divided into records of constant longitude. Each record contains a record location identifier and the

terrain elevation values which span the degree square from south to north at the given longitude. The interval between elevation values for standard DTED is three arcseconds. Overlap is provided between adjacent data files by adding an extra elevation value at the top of each record. Therefore, each record contains 1201 elevation values (3600 arcseconds per degree divided by three arcseconds per value, plus one overlap value). The records are arranged within the file in a similar manner from west to east, so that there are 1201 records spanning the width of the data file. Elevation values are read from each record from south to north, and records are read from west to east within the file (7:83-85). Figure 9 illustrates the structure of a typical data file.

For any location on the earth, three arcseconds in latitude provide a distance interval of approximately 300 feet (93 meters) between elevation values. At the equator, the longitudinal (east-west) distance interval is identical to the latitude interval. However, the farther one moves away from the equator, the more the longitudinal distance between elevation readings decreases, so that at the North or South Pole, the interval between readings would be zero. To compensate for this undesired increase in data density at higher latitudes, the longitudinal interval between DTED readings is changed at latitudes of 50, 70, 75, and 80 degrees, north and south. For instance, at 50 degrees, the east-west interval between elevation measurements is increased to six arcseconds; at 75 degrees, the longitudinal interval is increased to 12 arcseconds. These changes reduce the number of records in each data file to 601 above 50 degrees, and 301 above 75 degrees. No change is made to the number of elevation values per record, since north-south (meridian) distances remain constant for all locations (7:1-2).

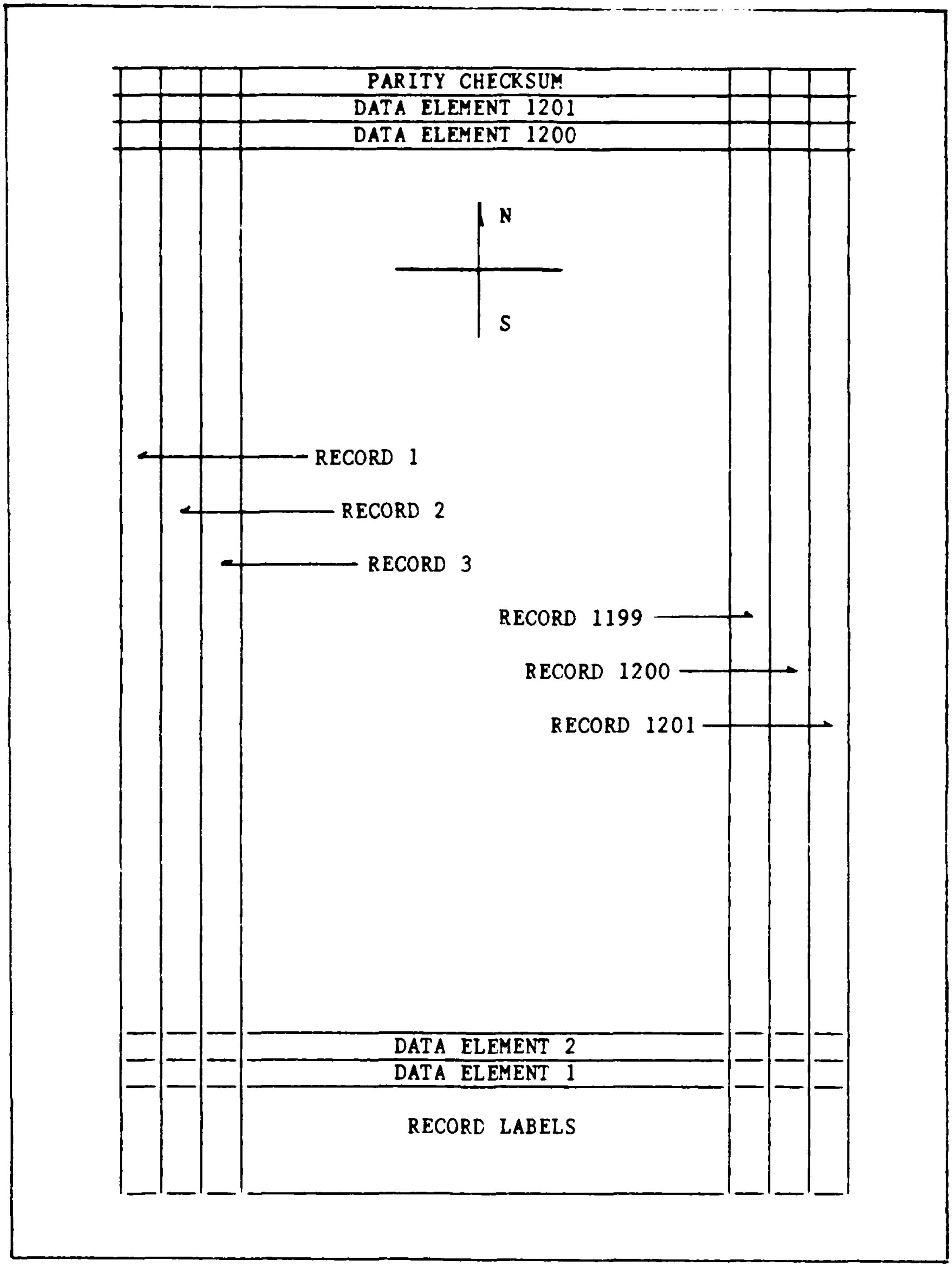


Figure 9. Structure of a DTED File.

ASD/ENSSE personnel have been using DTED for various projects for some time (22). They use their own computer software to group these basic DTED files into 2.5 by 7 degree data files, again labeled according to the coordinates of the southwest corner of the file. ASD/ENSSE made these data files available to the authors for this research (22).

Transformations

SAM Site Selection. Two terrain types were selected for analysis, the "Fulda Gap" area and the North German Plain. Their corresponding data files were obtained from ASD/ENSSE (49 degrees North Latitude/6 degrees East Longitude, and 52 degrees North Latitude/6 degrees East Longitude). These files contained terrain data for both East and West Germany. Next, twenty suitable SAM sites were chosen from each terrain area, as listed in Table II. These sites are all located on higher terrain that should afford good fields of view of approaching aircraft, yet should be reasonably accessible to mobile SAM systems. Overlap of SAM lethal zones was minimized within the geographic constraints of the terrain type. Within these criterion, the SAM sites were chosen based on the authors' combined experience of more than 2500 hours of flying tactical fighters, with substantial training emphasis on dealing with the SAM threat.

These forty SAM sites were initially selected by studying 1:250,000 scale Joint Operations Graphic (Air) ("JOG") charts, available from DMAAC. However, since the scale of the DTED is more precise than JOG charts, these SAM site locations had to be pinpointed in the digital terrain data. Two steps were required to precisely locate the SAM sites in the digital data:

TABLE II

SAM Sites Chosen for Data Base

	Site	North Latitude (Deg,Min,Sec)	East Longitude (Deg,Min,Sec)
	Hill 3117	50, 29, 58	9, 56, 13
	Hill 2343	50, 44, 45	10, 06, 17
	Hill 1729	50, 45, 15	9, 42, 10
	Hill 1588	50, 27, 22	9, 42, 00
	Hill 1650	50, 42, 38	9, 58, 24
	Hill 2382	50, 38, 17	10, 03, 42
	Hill 2067	50, 46, 53	10, 02, 00
Fulda	Hill 3045	50, 22, 23	9, 58, 48
	Hill 1726	50, 25, 42	10, 41, 41
Gap	Hill 1759	50, 29, 12	10, 27, 54
	Hill 1814	50, 43, 08	9, 50, 32
Area	Reinhards	50, 38, 54	9, 53, 34
	Hill 1621	50, 33, 15	9, 32, 11
	Autobahn	50, 34, 15	9, 42, 56
	Hill 1250	50, 15, 24	10, 33, 36
	Hill 1447	50, 17, 14	10, 02, 30
	Hill 2464	50, 35, 21	10, 16, 14
	Tower Site	50, 22, 36	10, 21, 24
	Hill 2536	50, 32, 12	9, 13, 46
	Hill 1476	50, 43, 45	9, 19, 20
	Hill 203	52, 39, 52	10, 46, 33
	Hill 213	52, 49, 40	8, 13, 26
	Hill 240	52, 52, 34	7, 31, 48
	Hill 69	53, 14, 10	8, 14, 25
	Hill 108	53, 30, 34	9, 07, 24
	Hill 200	53, 00, 45	9, 24, 00
	Hill 125	53, 01, 15	8, 27, 20
North	Hill 492	52, 52, 19	9, 52, 06
	Hill 220	52, 52, 11	9, 28, 18
German	Hill 85	52, 43, 00	9, 39, 20
	Hill 315	53, 41, 12	11, 18, 03
Plain	Hill 325	53, 38, 00	10, 20, 18
	Hill 509	53, 24, 30	9, 52, 00
	Hill 299	53, 49, 00	10, 02, 00
	Hill 200	53, 16, 21	9, 08, 30
	Hill 554	53, 10, 03	9, 56, 30
	Hill 341	53, 27, 30	10, 50, 08
	Hill 466	53, 02, 52	10, 54, 30
	Hill 584	53, 17, 51	11, 54, 20
	Hill 395	53, 27, 51	12, 04, 00

Step One. The appropriate 2.5 by 7 degree DTED file had to be loaded into core memory by executing a command file provided by ASD/ENSSE, named SETUPSAM.COM.

Step Two. The coordinates of the SAM site had to be refined by running a second ASD/ENSSE program named SITELOOK. The SAM site coordinates chosen from the JOG charts were input to SITELOOK, which produced a 61 X 61 matrix of DTED elevation points, centered on the input site coordinates. If by chance the highest point on the hill selected from the JOG chart perfectly matched the center elevation point of this 61 X 61 DTED matrix, the search for the optimum site location on this hill was ended. Usually, however, since the elevation values in the DTED are more refined than on a JOG chart, one would find that the DTED centerpoint initially selected was not the highest point in the vicinity. By inspecting the other elevation values in the 61 X 61 matrix, one could identify the highest point on this hill, and determine more correct coordinates for that high point. SITELOOK would then be run again to ensure that these new coordinates were correct. This step was also an important validation step, because one could compare elevations at the same location in the DTED and on the JOG chart. If significant differences occurred, one would suspect that the 2.5 by 7 degree DTED file was not correct for some reason. ASD/ENSSE support was relied on exclusively to solve such discrepancies.

Line-of-Sight Determination. Once the SAM sites were precisely located by SITELOOK, the next step was to determine where terrain would or would not mask an aircraft from the SAM radar. ASD/ENSSE has a large computer program, named SITESPE, that can determine these line-of-sight conditions from the DTED file. SITESPE accounts for curvature of the earth, radar horizon, and multipath angle. Given aircraft altitude and

specific coordinates for a SAM site, it will:

1. Load DTED terrain values in 0.05 nautical mile increments (about every 300 feet) from the SAM site out to a range of 30 nautical miles along specified radials originating at the SAM site.

2. Compute mask angles along the radials, and determine if a clear radar line-of-sight exists between the SAM site and a position defined by a specific radial/radial distance/altitude AGL. At each 0.05 NM increment along the radial, SITESPE will determine if a clear line-of-sight exists (which is coded as a "1" at that radial range), or if the position is masked from the radar field of view (which is coded as a "0"). Thus, each radial will have 601 "1"s and/or "0"s associated with it, since:

$$(30\text{NM})[(1\ \text{reading})/.05\text{NM}] + (1\ \text{reading for range}=0) = 601\ \text{readings}$$

These readings are stored in an array with dimensions:

ROWS	X	COLUMNS
(number of radials)	by	601

This research effort used 360 radials (one at each degree) at each SAM site. Therefore, a 360 X 601 matrix of "1"s and "0"s was generated for each altitude of interest at each SAM site. Matrices for six altitudes above ground level (50, 100, 250, 500, 750, and 1000 feet) were generated for each site. These line-of-sight determinations represent the first layer of data transformation required in this project.

For a single SAM site, these line-of-sight values are not random variables. However, when multiple SAM sites are sampled, line-of-sight can be treated as a random variable, as can be visualized from Figure 10.

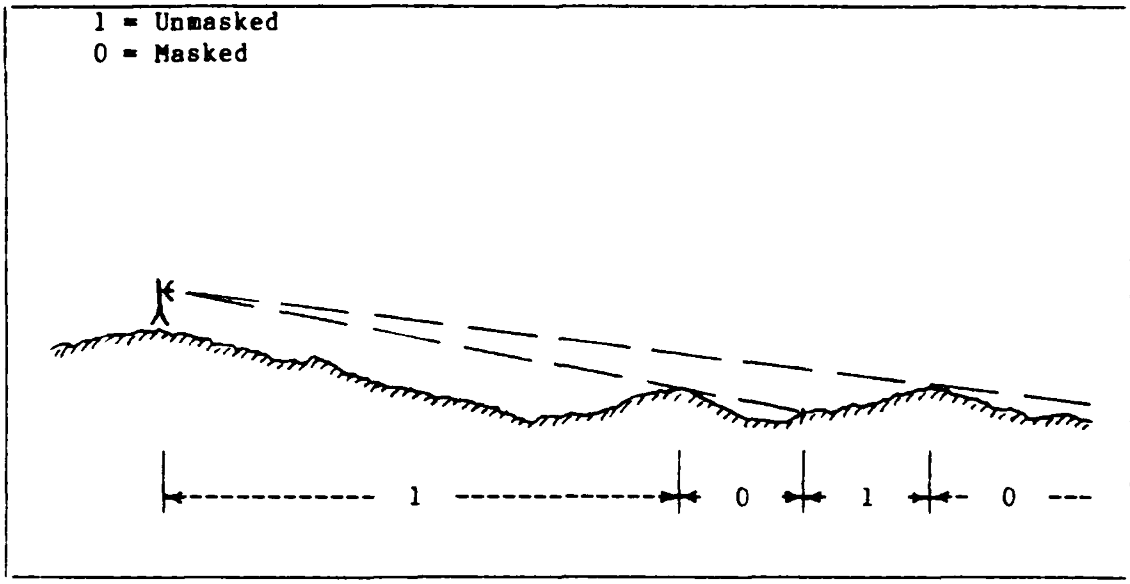


Figure 10. Line-of-Sight as a Random Variable.

If individual SAM sites are optimally located, however, unmasked values would predominate near the center of the SAM's area of coverage, while masked values might predominate toward the periphery, depending on the terrain type and aircraft altitude.

Masked/Unmasked Distances. The next layer of data transformation depended on what input was needed for the terrain-effects simulation model. The question that the simulation model needed the terrain model to answer was not simply whether the SAM radar had line-of-sight with the target, but rather how long the SAM radar maintained line-of-sight. If the length of the line-of-sight intervals were input into the simulation model, it could compute whether the SAM site had enough time to launch and guide a missile to the target before the aircraft was remasked by terrain. The next question was, should the line-of-sight interval be measured in terms of time or distance? The simulation model would use several variables, including aircraft airspeed, missile airspeed, and range between the SAM site and the target. Each of these factors would

affect whether line-of-sight was maintained for a sufficient time to allow missile intercept to be completed. Since the velocity of the SAM and the aircraft were variables, the terrain model measure of merit would have to be in terms of either time or distance, since:

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$

Since the time an aircraft would be masked or unmasked varied with each aircraft velocity setting, Masked/Unmasked Distance was chosen as the measure of merit for the terrain model, because it did not depend on aircraft velocity. Although time could have been used, it would have involved unnecessary computation. Data points would have had to be collected at a set speed value, and then converted if times for other than the data collection speed were desired. This would have involved an intermediate calculation of distance anyway, as shown in the following expression:

$$\text{Desired Masked or Unmasked Time} = \frac{\text{(Base Case Time)(Base Case Speed)}}{\text{(Desired Speed)}}$$

$$= \frac{\text{Distance}}{\text{Desired Speed}}$$

$$= \frac{[(\text{min})(\text{nm/min})]}{(\text{nm/min})} = \frac{\text{nm}}{\text{nm/min}} = \text{min}$$

Therefore, the second layer of data transformation involved determining the masked and unmasked distances that an aircraft would fly across each SAM site at each of the six altitudes of interest. Obviously, the assumption that the aircraft would fly a straight, non-maneuvering flight path through the SAM site was important. As discussed earlier in the geometric model, these flight paths could be defined by their Radius of Closest Approach (RCA) to the SAM site. Since RCA is actually a continuous variable, it would be desireable to analyze every

possible flightpath that crosses the SAM site's lethal envelope. Since this is computationally impossible, flightpaths were analyzed in RCA increments of 500 meters, with the concurrence of Lt Col Robert Might, HQ USAF/SAGF, who originally requested this study (18).

To generate the required masked and unmasked distances, a Fortran subroutine called DATAFIND was added to SITESPE, the same program that generated the 360 X 601 data matrices. DATAFIND is found in Appendix D. The subroutine begins by defining the aircraft's initial position. It computes the initial radial the aircraft is on, as defined by the lethal radius of the SAM system, and the given RCA. It refers to the row of the 360 X 601 matrix corresponding to the computed radial, and determines if an object at the specified altitude would be masked from the radar by reading a "1" or a "0" at the range just prior to or at the radar-to-aircraft range. It then advances along a chord (defined by the RCA) across the circle for which the radius is the lethal radius of the SAM system. Progression along the chord occurs as the radial of analysis is incrementally advanced one radial at a time. If the unmasked or masked (1 or 0) status does not change as the radials are incremented, the subroutine accumulates distance along the chord and continues incrementing radials. When the masked/unmasked reading changes between two radials, the subroutine writes to a file the RCA, altitude, distance start angle, distance, a "masked" or "unmasked" code, and the start point radial. It then repeats the process for the next masked or unmasked condition. When the full length of the chord is reached, the subroutine switches to the other side of the SAM site and repeats the process at the same RCA. Figure 11 shows the subroutine progression and distance start angle convention. This process is repeated for all specified altitudes

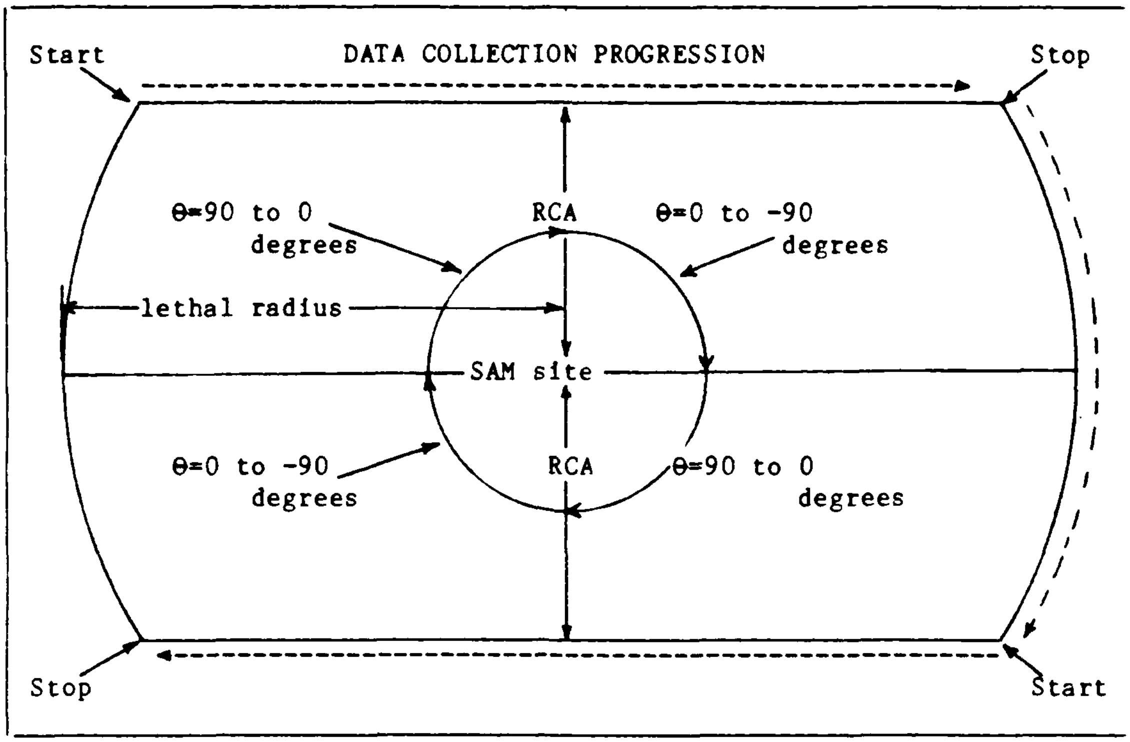


Figure 11. Data Generation Chronology and Angle Convention

for which a 360 X 601 data matrix exists, increments to the next RCA, and starts over. Data was gathered out to a range of 55,500 meters, or about 30 nautical miles, from the SAM site.

DATAFIND was first written as a stand-alone Fortran source program. It was verified by contriving a 360 X 601 matrix, and testing the program output with manually calculated results. The LIOS variables in the code listing refer to the 360 X 601 matrices generated by the ASD/ENSSE SITESPE code.

49 Cell Terrain Model. In the third layer of data transformation, the masked and unmasked distances generated by DATAFIND were sorted and grouped, using software written by the authors, into a format compatible with the AID statistical analysis package. This sorting process assembled the data from all twenty SAM sites per terrain type, producing data that was representative of the entire area of terrain analyzed. For

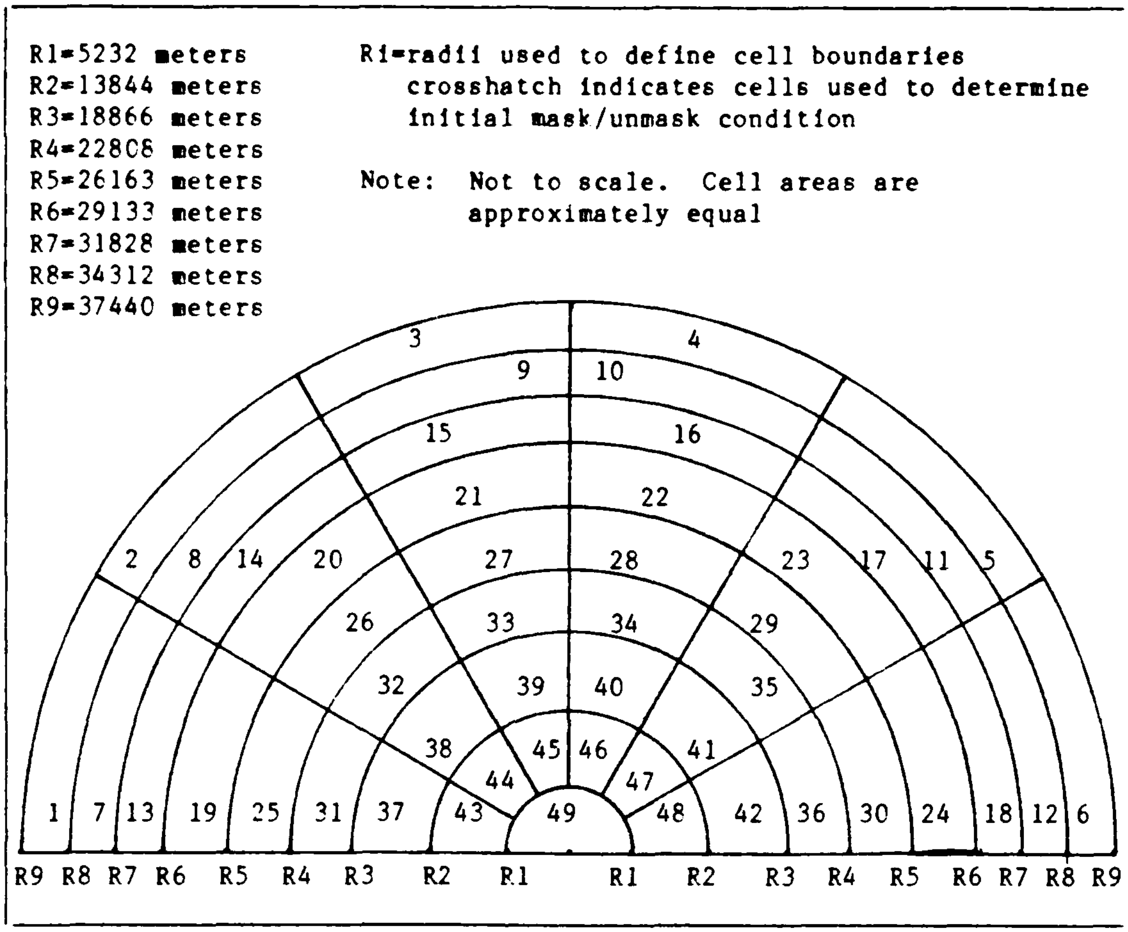


Figure 12. 49 Cells for Grouping Masked/Unmasked Distance Distributions.

each altitude, the masked distances per terrain type were grouped into 49 cells, and the unmasked distances per terrain type were grouped into a second set of 49 cells, in the manner shown in Figure 12. Because of the six altitudes, two terrain types, and two distance types involved, a total of twenty-four 49-cell models were created. Choosing the cells in this manner improved the homogeneity and continuity of the stochastic distributions of the data. The cells are all equal in size, except for the outer ring, which was slightly expanded to include more data points. The exact size of the cells is not of particular consequence. The radius of the cells is measured in meters, so that the outer limit of the 49

cell model extends to approximately 20.2 nautical miles. This distance was taken as a practical upper limit on terrain effects, data density, and typical SAM system range capability at low altitude.

Other sorting schemes besides the 49 cell model were attempted, without satisfactory results. The problem was that the lengths of these masked and unmasked distances have different distributions throughout the SAM system's coverage area. As discussed before, although line-of-sight values are random variables, the target tends to be in sight, or unmasked, more near the center of the SAM system's envelope, and less toward the edges of the SAM system's envelope. Masked distances, of course, occur in a reciprocal fashion. Thus, masked and unmasked distances are not uniformly distributed throughout the SAM system's coverage area. A categorization scheme that sorts these distances only according to angle-off from the SAM system (that is, "pie" sectors) was definitely inadequate, because it did not account for range between the SAM site and the target. Likewise, schemes that accounted for range and not angle-off also proved inadequate. The 49 cell model yielded good results, but similar variations, such as a 37 cell model or 55 cell model, may have worked just as well. The 49 cell model also provided good data density when sampling from 20 SAM sites per terrain type.

Terrain Model. In the final data transformation, the files thus constructed were analyzed with AID to determine the distribution of masked/unmasked distances (as appropriate) for each data cell. The Kolmogorov-Smirnov (K-S) test with an alpha level of 0.1 was used to test goodness of fit of the theoretical distribution. Approximately half of the data files initially passed the K-S test when fitted to theoretical probability distributions. If a file failed to pass the K-S test for all of the available distributions, it was subdivided into smaller, more

homogeneous data groups. Approximately half of the files that initially failed a K-S test were successfully fitted to theoretical distributions after they were subdivided. In all cases, including subdivided files that could not pass a K-S test with any of the available distributional assumptions, the theoretical distribution with the best K-S test statistic was used in the subsequent model. This approach prevented the authors from having to fit a considerable number of data cells to empirical distributions, yet produced similar results. A majority of the resulting distributions were Log Normal, with the remainder being Beta, Weibull, Gamma, Normal, or Uniform distributions. Appendix C contains an example of how these distributions were coded for the terrain model, and Appendix F and G provide tables summarizing the final distributions used.

An example of using AID to "fit a curve" to a masked distance is shown in Figure 13. The corresponding Kolmogorov-Smirnov goodness-of-fit test is shown in Figure 14. It should be noted that considerable time was required to fit these theoretical distributions. Fitting twenty-four 49 cell models took in excess of three weeks.

The basic terrain model, then, is made up of this collection of 49-cell data groupings. The simulation model goes on to use this underlying model to determine the impact of terrain on the aircraft-SAM encounter. However, the basic terrain model, as a method of characterizing entire types of terrain, should be usable in a large variety of other models.

Before leaving the terrain model, it is instructive to make two observations:

Distribution Parameters. There is no definitive trend in the parameters of the theoretical distributions (see Appendix F and G). While some weak tendencies may appear in some of the parameters of the

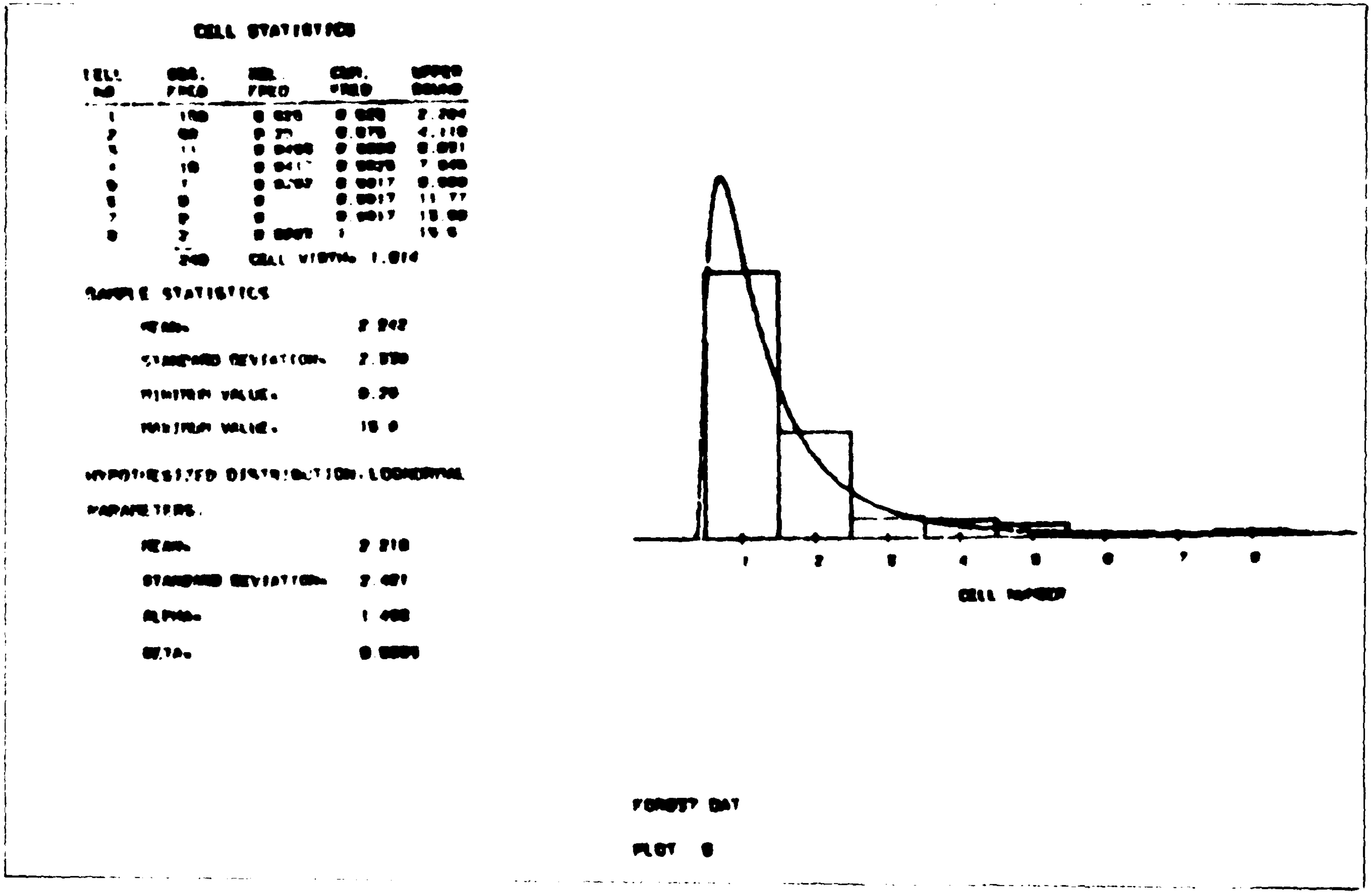


Figure 13. Typical Log Normal Distance Distribution.

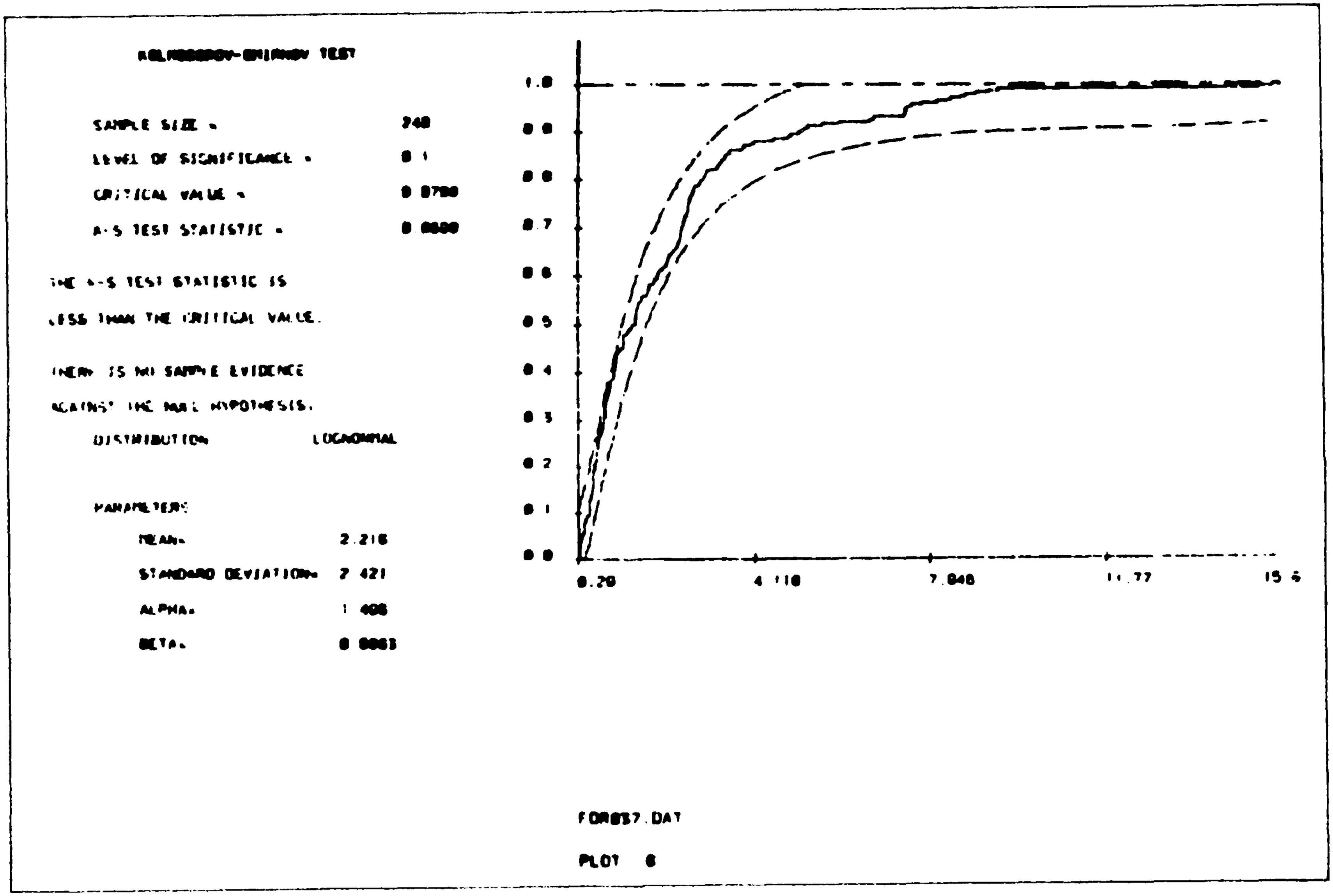


Figure 14. Goodness-of-Fit Test Results with AID.

masked and unmasked distance distributions, there are more than enough exceptions to prevent one from making overall generalizations from these distributions. On the other hand, not attempting to generalize these distributions also keeps one at a more fundamental, accurate data base level.

Distribution Type. Finally, it should be noted that one might intuitively expect the distance distributions to be predominantly exponential instead of log normal. In the real world, considering variable terrain, one would expect to see a very high number of extremely short masked or unmasked distances, decreasing continuously to only a few very long masked or unmasked distances. There are two probable reasons why log normal rather than exponential distributions predominated: (1) The DTED itself is not continuous. Its smallest increment is generally 300 feet. (2) The data collection geometry of stepping from one degree radial to the next degree radial prevents the minimum distance flown from being infinitely small, particularly at large slant ranges from the SAM site. The result of these two factors is that, as the masked and unmasked distances measured approach the lower limit of zero, their number actually begins to decrease at some point, rather than continuously increase. Again the authors chose to accept the data exactly as collected rather than introduce errors by unwarranted generalizations. As a result, the terrain model that results from these 49 Cell models should very closely approximate the terrain types studied.

Conclusion

Several steps were required to transform digital terrain data into a form that describes the terrain attributes of an entire geographic area. The system of 49 cell models that was derived appears to perform this

task well, but it has yet to be validated by actual experiment or duplicating analyses. This terrain modeling system was used as the data base for the terrain effects simulation model discussed in Chapter Three to produce the ultimate measure of merit, Number of Engagements per Aircraft per Nautical Mile. A regression model was developed from these simulation results to maximize predictive capability on the effects of terrain on the aircraft-SAM system encounter. A full factorial design was also applied to these simulation results to explain the impact and interaction of the individual factors that define terrain effects.

V. Analysis and Findings

Introduction

The terrain-effects simulation model discussed in Chapter Three used the 49-cell terrain models to produce the ultimate measure of merit, Number of Engagements per Aircraft per Nautical Mile, for each terrain type. The output from the terrain effects simulation model was then analyzed using two methods, a full factorial design and multiple regression. The full factorial design was employed to examine how aircraft and SAM system parameters contribute to the impact of terrain on the aircraft/SAM system encounter. Multiple regression was used to produce an equation that could be used by higher level models to predict the Number of Engagements per Aircraft per Nautical Mile that would occur in each terrain type. This chapter will discuss the factorial design and regression analyses, their findings, and the conclusions and implications that can be drawn from these findings.

Choice of Analysis Methods

Before discussing the factorial design and regression analyses themselves, one should address why these two separate methods were chosen when, in fact, they are very closely related. Factorial design relies on analysis of variance (ANOVA), and Montgomery points out that "... every analysis of variance model can be expressed in terms of a regression equation" (19:113). Montgomery goes on to develop a regression significance test that can be used for hypothesis testing, just as one would normally use in ANOVA (19:113). The real question, however, is what the objectives of the analyses are. Two objectives were involved at this point in the research: (1) to develop a concise method of

predicting terrain effects, for use in larger models, and (2) to explain what the key factors were, and how they interacted to define terrain effects on the aircraft-SAM encounter. To meet the first objective, the most efficient approach would be use of a single equation. Montgomery points out that "The general approach to fitting equations to data is regression analysis" (19:106). On the other hand, Montgomery states that factorial designs are the most efficient method for studying the effects of individual factors (19:189). Therefore, both analysis methods were used, each for a separate objective. In fact, their employment overlapped, because the ANOVA provided valuable insight for the regression equation. As one would expect, their results are mutually supporting.

Factorial Design

Each run of the terrain effects model simulated 50 individual aircraft crossing a SAM threat area. Simulation runs were made for every possible combination of factor treatments, and two replications were made of each simulation run, using different random number seeds. A full factorial design was then executed on the independent variables in the simulation model, using BMDP Program P2V.

BMDP Program P2V performs an analysis of variance on fixed-effects factorial designs (9:359). Unless specified otherwise, it assumes that all interactions are to be included in the ANOVA model. Computationally, P2V obtains each sum of squares as the difference in the residual sums of squares of two regression models. For each factor with "k" levels, it generates "k - 1" dummy variables. Interactions between factors are represented by the products of their dummy variables. P2V first fits the regression model containing all the dummy variables for the factors and

their interactions, and then fits the model containing all dummy variables except those of the main effect or interaction being tested. The difference between residual sums of squares of the two models is the sum of squares reported (9:363).

Fulda Area Analysis. The ANOVA table produced by P2V for Fulda-area terrain effects is shown in Table III. Because of computer memory constraints, the only altitude treatments analyzed were 50, 250, 500, and 750; 100 and 1000 foot data were omitted. Using an alpha level of 0.05 to determine statistical significance, and using either the F-statistics or the Tail Probability statistics, one can immediately make several observations from Table III:

1. All five main factors are significant, as well as their two-way interactions. None of the four and five-way interactions are significant, and neither are about half of the three-way interactions.

2. The most important single factor by far is SAM system delay, followed in order by RCAMAX (threat density), altitude, aircraft speed, and missile speed (MISPEED). Missile speed is not as significant as the two-way interaction between RCAMAX and delay (rd).

3. The order of significance of the two-way interactions corresponds to the order of significance of the single factors. The interaction between RCAMAX and delay (rd) dominates, while the interaction between aircraft speed and missile speed (sm) is less significant than the three-way interaction between delay, RCAMAX, and altitude.

Montgomery points out that, when interactions are large, the corresponding main effects have little practical meaning. Further, "In the presence of significant interaction, the experimenter must usually

TABLE III

ANOVA Table for Fulda-area Terrain Effects

ANALYSIS OF VARIANCE FOR DEPENDENT VARIABLE - Number of Engagements

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROB.
MEAN	221991988.89	1	221991988.89	128881.86	.0000
altitude	37185782.10	3	12395260.70	7196.31	.0000
speed	8585273.67	3	2861757.89	1661.45	.0000
rcamax	31574950.18	2	15787475.09	9165.73	.0000
mispeed	3055732.93	2	1527866.46	887.03	.0000
delay	46054769.92	2	23027384.96	13369.01	.0000
as	998774.35	9	110974.92	64.43	.0000
ar	2355203.61	6	392533.93	227.89	.0000
sr	1020440.10	6	170073.35	98.74	.0000
am	335869.94	6	55978.32	32.50	.0000
sm	80126.10	6	13354.35	7.75	.0000
rm	298756.25	4	74689.06	43.36	.0000
ad	3516282.92	6	586047.15	340.24	.0000
sd	1415287.38	6	235881.23	136.95	.0000
rd	14099611.57	4	3524902.89	2046.45	.0000
md	1222758.96	4	305689.74	177.47	.0000
asr	57958.69	18	3219.92	1.87	.0167
asm	14572.27	18	809.57	.47	.9696
asd	89879.12	18	4993.28	2.90	.0001
arm	8542.94	12	711.91	.41	.9584
ard	720960.15	12	60080.01	34.88	.0000
srm	19520.90	12	1626.74	.94	.5020
srd	378281.97	12	31523.49	18.30	.0000
amd	74454.76	12	6204.56	3.60	.0000
smd	32013.99	12	2667.83	1.55	.1039
rmd	321672.23	8	40209.02	23.34	.0000
asrm	20689.18	36	574.69	.33	.9999
asrd	31313.14	36	869.80	.50	.9931
asmd	28110.79	36	780.85	.45	.9976
armd	17524.69	24	730.19	.42	.9931
srmd	19133.02	24	797.20	.46	.9872
asrmd	33859.63	72	470.27	.27	1.0000
ERROR	744096.50	432	1722.44		

$F(.05,2,432) = 3.00$ $F(.05,9,432) = 1.88$
$F(.05,3,432) = 2.60$ $F(.05,12,432) = 1.75$
$F(.05,4,432) = 2.37$ $F(.05,18,432) = 1.62$
$F(.05,6,432) = 2.10$ $F(.05,36,432) = 1.42$

examine the levels of one factor, say A, with levels of the other factors fixed to draw conclusions about the main effect of A" (19:191). By using this technique, one can readily understand the impact of each individual factor when its treatment levels are plotted against the response variable, Number of Engagements. (Note that the response variable is not yet scaled per aircraft per nautical mile). The factors will be discussed in order of significance. When the other factors are held constant, their treatment levels will be:

Delay:	5 seconds	(.0833 minutes)
RCAMAX:	25926 meters	(13.85 nm)
Altitude:	250 feet AGL	
Speed:	8 nm/min	(480 nm/hour)
Missile Speed:	22.3 nm/min	

SAM System Delays. Figure 15 shows the effect of SAM system delays on the number of engagements achieved. The results are intuitively appealing, because as delay decreases, more engagements occur. Note that almost twice as many engagements occur at the zero treatment level than at the 5-second level.

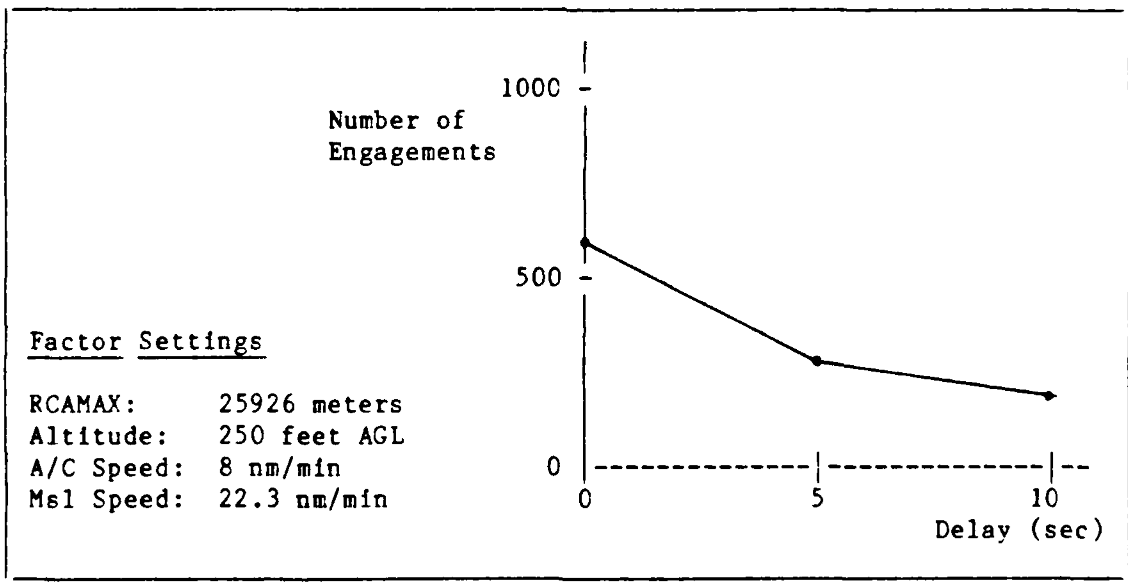


Figure 15. Main Factors -- Number of Engagements versus Delay (Fulda).

RCAMAX. The impact of RCAMAX, or threat density, is shown on page E-1 of Appendix E. The values for number of engagements, and the slope of the lines connecting these values, is very similar to Figure 15 for this particular setting of the treatment levels of the other factors. As RCAMAX increases, threat density decreases, and Number of Engagements decreases. Again, this result is logical.

Aircraft Altitude. The impact of aircraft altitude on the number of engagements is distinctly non-linear. This fact shows up more in the

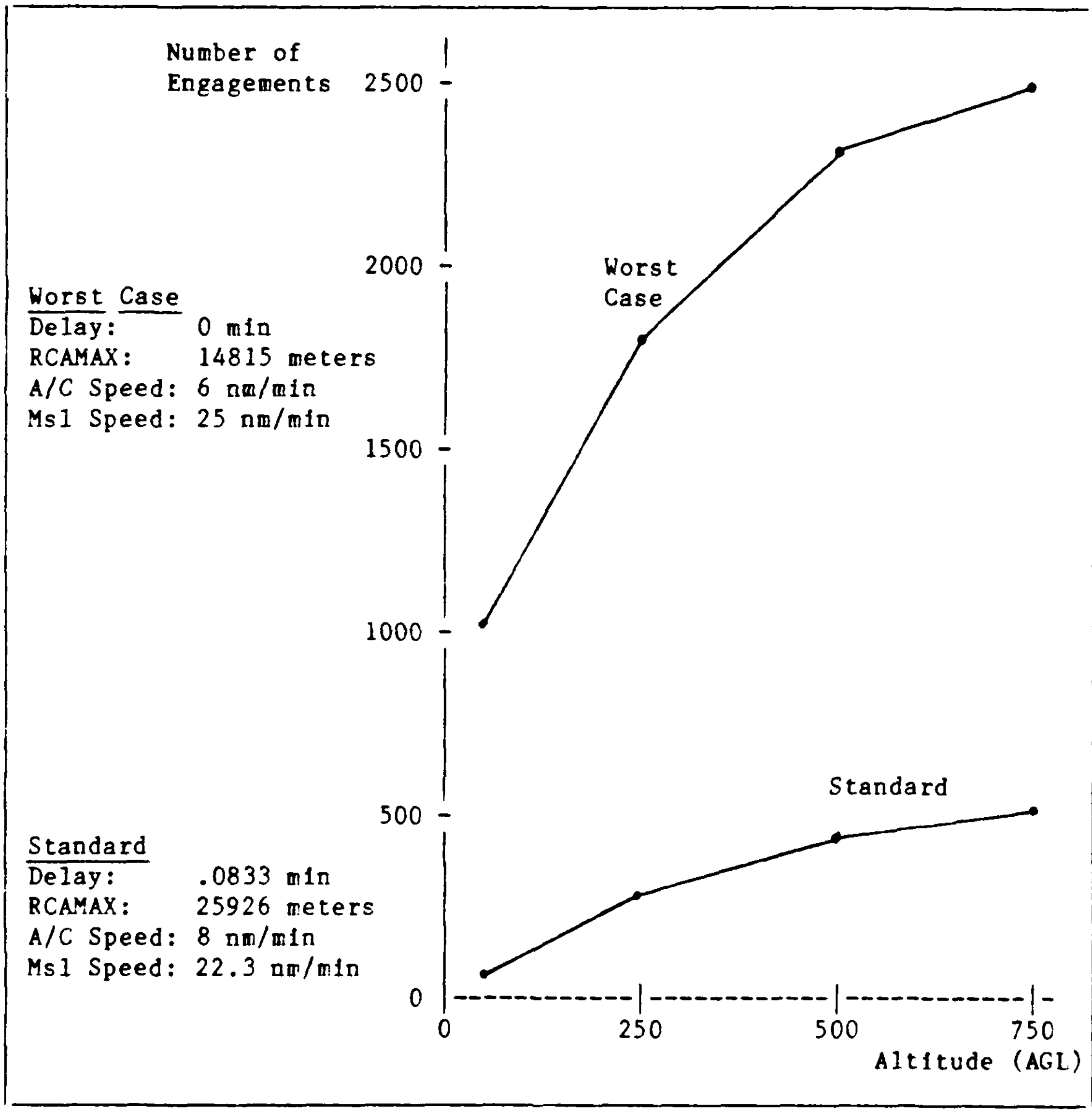


Figure 16. Main Factors -- Number of Engagements versus Aircraft Altitude (Fulda).

worst-case depiction in Figure 16 than in the depiction for the standard values. There are definite benefits to flying below 500 feet AGL, and the lower, the better; above 500 feet, the influence of the altitude factor begins to level out. In other words, terrain effects have marginal impact for aircraft flying above 500 feet AGL in areas like Fulda. The number of engagements experienced appears to approach some upper limit at higher altitudes for this combination of factor settings. One would intuitively expect an outcome like this, but would have difficulty selecting significant altitude values on an intuitive basis. As a further point, note that the increase in engagements per increase in altitude looks somewhat like the cumulative distribution function (CDF) of an exponential distribution. Further study is required, but one might suspect that the number of engagements experienced decreases exponentially as a function of altitude once terrain effects begin to occur, at least in Fulda-type terrain.

Aircraft Airspeed. The effect of aircraft airspeed on the number of engagements can be seen on page E-1 of Appendix E. Higher airspeeds reduce the number of engagements. The impact of aircraft airspeed is basically linear, without much slope to the line at the standard factor settings. When SAM system delays are reduced to zero, aircraft airspeed becomes more significant, indicating a strong interaction between factors.

Missile Speed. Missile speed as a factor is graphed in Appendix E, page E-2. It had less impact as a factor than aircraft airspeed. It also had a linear relationship to the number of engagements, with little slope to its line at the standard settings. Increasing missile speeds resulted in more engagements, which is logical.

Factor Interactions. All of the two-way factor interactions were significant, with SAM System Delay playing the predominant role. The five most significant interactions are depicted on pages E-1 through E-3 of Appendix E. Several generalizations are readily apparent:

1. The strongest interactions occur at closer ranges (lower RCAMAX), lower altitudes, and lower delay factor settings.

2. The impact of SAM system delays in terms of number of engagements was most significant at closer ranges, higher altitudes, slower aircraft airspeeds, and higher missile speeds. These results are reasonable.

In perfecting the regression model for the Fulda-type of terrain, several transformations were required to compensate for non-constant variance and non-linearities. The graphic result of those transformations is shown in Appendix E, pages E-4 and E-5. One can see that such factors as altitude a now linear. These graphs are somewhat more difficult to interpret, however, because of the logarithmic scale on Number of Engagements and the altered scale for altitude.

To conclude the factorial analysis of Fulda-type terrain, one can say that the individual and collective results of the analysis make intuitive sense. This outcome speaks highly of the validity of the models used. The impact of several of the factors in the aircraft-SAM system encounter are now quantifiable.

North German Plains Analysis. The ANOVA table produced by BMDP P2V for terrain effects on the North German Plain is shown in Table IV. Because the data base thins out rapidly above 250 feet AGL, the following analysis only deals with altitude treatment levels of 50, 100, and 250 feet AGL. Using an alpha level of 0.05 to determine statistical significance, one can again make certain observations:

TABLE IV

ANOVA Table for North German Plain Terrain Effects

ANALYSIS OF VARIANCE FOR DEPENDENT VARIABLE - Number of Engagements

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROB.
MEAN	300325495.89	1	300325495.89	425095.44	.0000
altitude	4156657.26	2	2078328.63	2941.77	.0000
speed	10315961.69	3	3438653.89	4867.24	.0000
rcamax	19534380.89	2	9767190.44	13824.96	.0000
mispeed	2656045.03	2	1328022.51	1879.75	.0000
delay	50469213.72	3	16823071.24	23812.20	.0000
as	91045.35	6	15174.22	21.48	.0000
ar	144256.22	4	36064.05	51.05	.0000
sr	581717.97	6	96952.99	137.23	.0000
am	26558.27	4	6639.56	9.40	.0000
sm	45540.75	6	7590.12	10.74	.0000
rm	69614.18	4	17403.54	24.63	.0000
ad	295242.29	6	49207.04	69.65	.0000
sd	1312917.85	9	145879.76	206.49	.0000
rd	10100454.13	6	1683409.02	2382.78	.0000
md	994355.19	6	165725.86	234.58	.0000
asr	7339.73	12	611.64	.87	.5823
asm	2517.02	12	209.75	.30	.9898
asd	7221.74	18	401.20	.57	.9221
arm	2963.75	8	370.46	.52	.8383
ard	31285.18	12	2607.09	3.69	.0000
srm	8176.44	12	681.37	.96	.4822
srd	281366.65	18	15631.48	22.13	.0000
amd	9853.85	12	821.15	1.16	.3081
smd	30222.12	18	1679.00	2.38	.0013
rmd	153890.72	12	12824.22	18.15	.0000
asrm	4663.11	24	194.29	.28	.9998
asrd	9568.85	36	265.80	.38	.9997
asmd	8126.07	36	225.72	.32	1.0000
armd	4661.22	24	194.21	.27	.9998
srmd	15240.20	36	423.33	.60	.9693
asrmd	20306.01	72	282.02	.40	1.0000
ERROR	305203.50	432	706.48		

$F(.05,2,432) = 3.00$ $F(.05,9,432) = 1.88$
$F(.05,3,432) = 2.60$ $F(.05,12,432) = 1.75$
$F(.05,4,432) = 2.37$ $F(.05,18,432) = 1.62$
$F(.05,6,432) = 2.10$ $F(.05,36,432) = 1.42$

1. All five main factors are significant, as well as their two-way interactions. None of the four and five-way interactions are significant, and neither are about half of the three-way interactions.

2. The order of significance of the main factors has changed from the order that occurred in Fulda-type terrain. Aircraft altitude is now less significant than aircraft airspeed. The other factors retain their position in the hierarchy of significance (delay is first, threat density/RCAMAX is second, and missile speed is fifth). Threat density is much more influential as a factor now, however.

3. As a consequence of the change in order and significance levels of the main factors, the order and significance of the interaction terms have also changed.

Again an analysis will be made of the main factor effects and the predominant interaction effects. The treatment levels that will be used when the other factors are held constant will be:

Delay:	6 seconds	(.1000 minutes)
RCAMAX:	25926 meters	(13.85 miles)
Altitude:	100 feet AGL	
Aircraft Speed:	8 nm/min	(480 nm/hour)
Missile Speed:	22.3 nm/min	

<u>SAM System Delays</u>. Figure 17 shows the effect of SAM system delays on the number of engagements achieved. The results are similar to the Fulda-area results, except that the slope of the lines connecting the observations is steeper. The implication is that SAM system delays have more impact in flat terrain. This outcome is reinforced by the previous observation that, in Fulda-type terrain, delays had the most impact at higher altitudes. Thus, the less terrain is involved in the aircraft-SAM encounter, the more important SAM system delays become.

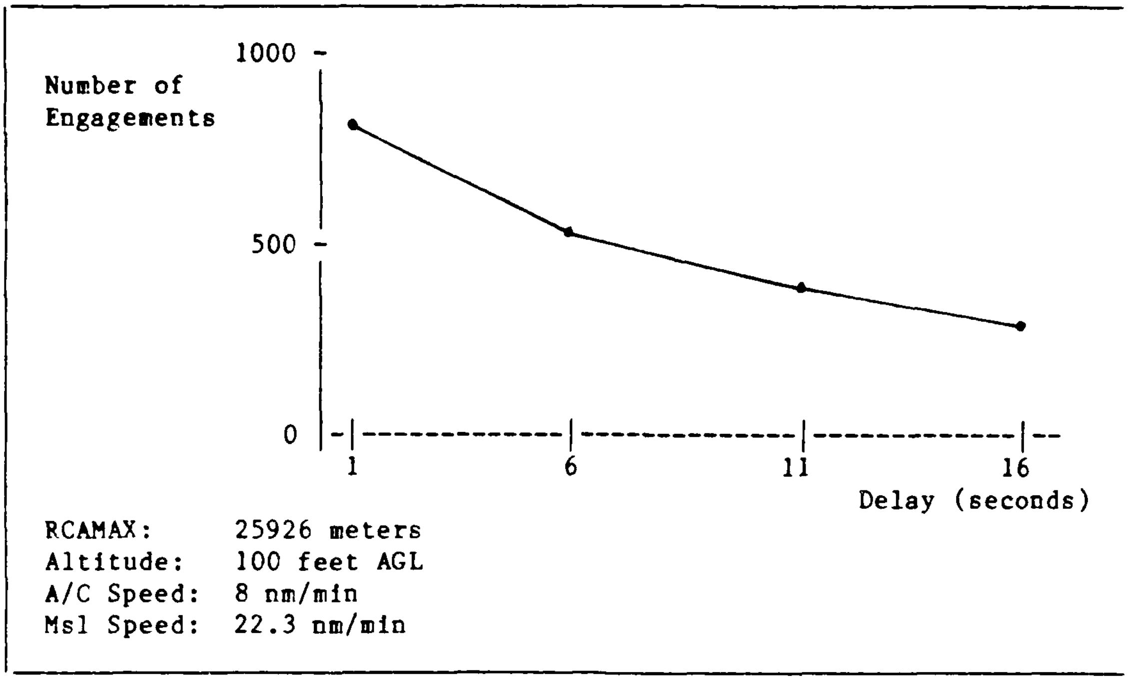
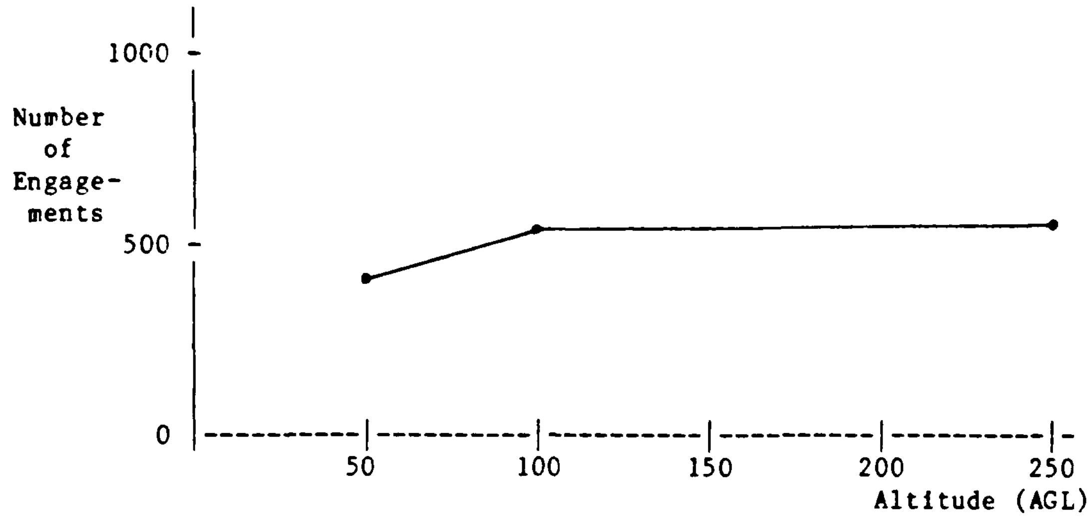


Figure 17. Main Factors -- Number of Engagements versus Delay (Plains).

RCAMAX. The impact of RCAMAX, or threat density, is shown on page E-6 of Appendix E. Its plot for the North German Plain is virtually identical to the plot for the Fulda area (page E-1), except that it is moved up the "Number of Engagements" scale, producing more engagements in the flatter terrain. This observation would imply that the threat density factor may be useful in categorizing terrain types, but further investigations should be made.

Aircraft Speed. The effect of variations in aircraft airspeed can also be seen on page E-6. Its plot is somewhat similar to the "Speed" plot for the Fulda area (page E-1), but the slope of its lines are steeper and higher up the "Engagements" scale, indicating that aircraft airspeed is considerably more important in flatter terrain.

Aircraft Altitude. The impact of aircraft altitude on the number of engagements is shown in Figure 18. Variations in aircraft altitude are only significant below 100 feet AGL. In other words, when aircraft



Factor Settings
Delay: 6 seconds
RCAMAX: 25926 meters
A/C Speed: 8 nm/min
Msl Speed: 22.3 nm/min

Figure 18. Main Factors -- Number of Engagements versus Aircraft Altitude (Plains).

altitude is above 100 feet in the North German Plain, terrain effects on the aircraft-SAM encounter are negligible, at least at these factor settings. This result is significantly different from the findings from Fulda terrain, where even above 500 feet AGL, aircraft altitude variations still had some impact on the number of engagements that occurred (see Figure 16). The hypothesized exponential relationship between decreasing aircraft altitude and Number of Engagements experienced is not as obvious in the Plains data, but is still possible and should be investigated further. Finally, it can be seen that the number of engagements experienced clearly converges to an upper limit at higher altitudes for these factor settings.

Missile Speed. Missile Speed as a factor is graphed in Appendix E, page E-7. Its plot is somewhat similar to the "Missile Speed" plot for

the Fulda area (page F-2), but the slope of its lines are steeper and higher up the "Engagements" scale, indicating that missile speed is somewhat more important in flatter terrain. Again, increasing missile speeds resulted in more engagements, a logical result.

<u>Factor Interactions</u>. All of the two-way factor interactions were significant for North German Plain data, just as in the Fulda data. Again, SAM System Delay dominated the interactions. The five most significant interactions are depicted on pages E-7 through E-9. The graph of Delay versus RCAMAX (page E-7) is the only one that shows strong interactions. The strongest interaction occurs at lower ranges and delay factor settings. This result is similar to the result from Fulda terrain with regard to range and delay factors. Fulda data, however, also demonstrated strong interactions involving the altitude factor; these interactions are not nearly as significant in the North German Plain data.

As a final point, one should compare the number of engagements that occur in the two terrain types at the same factor settings. This is possible by comparing Figure 16 and Figure 18 for values of 50 feet and 250 feet. The comparison is not exact, since the delay factor setting is 5 seconds in Figure 16, and 6 seconds in Figure 18. The results of this comparison are:

	Fulda	North German Plain
50′ AGL:	95	434
250′ AGL:	282	571

While this comparison may not be precise, it makes the point that terrain is very effective in masking aircraft from SAM systems in rugged areas like the Fulda region. This observation also lends credence to the overall validity of the models involved.

To conclude the factorial analysis of the North German Plain data, one can see that its results complement those of the Fulda data extremely well, without raising any contradictions. Again, this outcome increases one's confidence in the underlying models.

Regression Model

The regression model of simulation generated data represents the final form of this research. The response variable is the number of complete engagements per aircraft per nautical mile. This variable is computed for each data case generated by the simulation model. The number of lethal engagements (NENG) is divided by 50, since 50 runs were made for each replication/data case. The resulting value produces an expected number of lethal engagements per aircraft. When the expected number of lethal engagements per aircraft is divided by the average distance flown within SAM system coverage (ADIST), the resulting value gives expected number of lethal engagements per aircraft per nautical mile. The regression model is designed to produce this value with a transformation of the original NENG and ADIST variables. To apply the regression model, the aircraft flight parameters, SAM system parameters, and distance flown in SAM system coverage may be specified to produce an expected number of unmasked exposures during which a lethal engagement can occur.

Regression Model Development. Two regression models were developed. One model was developed using data from the simulation runs employing the Fulda area terrain model. The other regression model used data derived from simulations conducted with the North German Plain terrain model. Regression model development was an iterative process involving analysis of variance and all-subsets regression techniques.

Fulda Model Development. An analysis of variance model was produced initially to take a preliminary look at the data characteristics. It was anticipated that an ANOVA model would explain more variance than a regression model at first, since non-linearities could be accounted for (even though falsely) through interaction terms. This preliminary ANOVA was done specifically to look at the variance characteristics of the residuals versus predicted values using a relatively accurate model. The residual versus predicted plot reflected an "outward opening megaphone" tendency, calling for a variance stabilizing transformation of the response variable. A natural logarithm transformation was selected based on the approximately log normal distribution of the response variable, as determined through histogram analysis with appropriate AFIT VAX/VMS statistical software (19:91). This transformation worked very well. Figures 19 and 20 show the effect of this transformation. (In these Figures, A = 10 cases, B = 11 cases,..., and * = 36 or more cases.) The ANOVA was done with BMDP statistical software on the AFIT VAX/UNIX system.

An all-subsets regression was done along with the preliminary ANOVA run to see how well a linear model matched the data with no variable transformations. The adjusted R-squared statistic for the initial regression run (using an all-subsets regression statistical software package) for the Fulda model was approximately .63. The variance stabilizing (log normal) transformation to the response variable, implemented as a result of the ANOVA run, increased the adjusted R-squared to .83.

```
           .+.......+.X.....+.......+.......+.......+.......+.......+.....
           -                1                          1                 -
           -                       1   1                                 -
    100    +                 1      1                                    +
           -               1                  1    1                     -
           -        111    11     1   1  1    1                          -
           -            11113    1 1 1  1 1  1   1     1 1              -
  R        -       42 212 21  5  1 1  2   1 1                            -
  E        -     2 431115222  1 2  1 1  1 11             1               -
  S        -  134774429323143 1312 1     1      11                       -
  I        -159DCCCAJBA4A524 31  1    1   1 1                 1          -
  D 0.0   Y4**GKGEAI8C48A4222 4222                2                      Y
  U        -159DCCCAJBA4A524 31  1    1   1 1                 1          -
  A        -  134774429323143 1312 1     1      11                       -
  L        -     2 431115222  1 2  1 1  1 11             1               -
           -       42 212 21  5  1 1  2   1 1                            -
           -            11113    1 1 1  1 1  1   1     1 1              -
           -        111    11     1   1  1    1                          -
           -               1                  1    1                     -
   -100    +                 1      1                                    +
           -                       1   1                                 -
           -                1                          1                 -
           .+.......+.X.....+.......+.......+.......+.......+.......+.....
           0.00    400.    800     1200    1600    2000    2400    2800
                                                                PREDICTED
```

Figure 19. Residuals Versus Predicted Before Log Normal Transformation

```
           .....+.......+.......+.......+.......X.......+.......+.......+.
           - 1                                                           -
     .4    +                                                             +
           -                                                             -
           -                                                             -
           -       1       1                                             -
  R        -                 11     1           1                        -
  E        -1    1         1     11 1 1  1121 112 1 1      1             -
  S        -       1  2 2121    12132133 25241 152112  2 2431 21 1       -
  I        -          1 122111 42132  1236432A8AA77C895D74253323214121   -
  D   0.   Y      2   222      2  624 2446426AC488GQCMKAGECE8A66266442422 Y
  U        -          1 122111 42132  1236432A8AA77C895D74253323214121   -
  A        -       1  2 2121    12132133 25241 152112  2 2431 21 1       -
  L        -1    1         1     11 1 1  1121 112 1 1      1             -
           -                 11     1           1                        -
           -       1       1                                             -
           -                                                             -
           -                                                             -
    -.4    +                                                             +
           - 1                                                           -
           .....+.......+.......+.......+.......X.......+.......+.......+.
              -4.9    -4.2    -3.5    -2.8    -2.1    -1.4    -.70    0.0
                                                                PREDICTED
```

Figure 20. Residuals Versus Predicted After Log Normal Transformation

Subsequent regression runs were aimed at identifying and modeling any non-linear relationships between the independent variables and the response variable. The most dramatic non-linear response occured with changes in altitude. Based on the response variable versus altitude plot (to determine the general form of the transformation) and trial and error experimentation with the constant in the exponent, the following transformation of the altitude variable resulted in an adjusted-R squared statistic of .9507:

altitude=1-exp(-altitude/200)

Other significant non-linear relationships were not identified in any of the aircraft airspeed, RCAMAX, missile speed, and delay versus response plots.

Having attempted to improve the regression adjusted R-squared as much as possible through transformations to the response and independent variables, the next step was to identify and include any significant interaction terms. The ANOVA analysis was therefore repeated with these transformations incorporated. As a result, all three-way and higher interactions and three of ten two-way interactions were not significant at an alpha level of .05 (in contrast to the situation before variable transformations, where only the four-way and the five-way interactions were not significant). Correlation between the primary regressor variables and interaction terms (which were functions of the primary regressor variables) was anticipated, but not of particular concern, given the objective of maximum predictive capability in the final models.

Interaction terms were then sequentially added to the regression model in order of significance (as determined by the term's F statistic in the revised ANOVA). The functional form of the added interaction

terms was determined through a combination of judgement and trial and error. A "models comparison" technique, in which the significance of a term's contribution to R-squared is evaluated by comparing the following F statistic to a critical value for a given significance level, was used. (For one-at-a-time addition of terms, this technique is equivalent to a "t" statistic significance test for the added variable.)(13:71):

$$F = \frac{SSEr - SSEf}{SSEf} \cdot \frac{df}{dr - df}$$

where: SSEr = error sum of squares for the restricted model
SSEf = error sum of squares for the full model
df = degrees of freedom for the full model
dr = degrees of freedom for the restricted model

A significance level of .05 was used, resulting in three interaction terms being included in the Fulda regression model. The significant interactions included altitude & delay, altitude & RCAMAX, and RCAMAX & delay. The order of importance of all independent variables in the regression model (as determined by contribution to R-squared) is:

1. Altitude
2. RCAMAX
3. SAM system delay
4. Aircraft airspeed
5. Altitude & delay interaction
6. Missile speed
7. Altitude & RCAMAX interaction
8. RCAMAX & delay interaction

The final Fulda regression model has an adjusted R-squared of .97727. A summary of the model and its statistical characteristics are contained in Appendix F. The regression equation is:

$$\begin{aligned}\ln((neng/50)/adist) = {} & -1.327849 + (1.742054)[1-\exp(-altitude/200)] - \\ & (.177740)(aircraft\ airspeed) - \\ & (.0000613687)(rcamax) + \\ & (.0427086)(missile\ speed) - (14.6790)(delay\ time) + \\ & (.562587)(altitude{**}delay) + \\ & (.146851e{-}06)[(altitude/20){**}(rcamax/10000)] + \\ & (1.07174)[(rcamax/10000)(delay)]\end{aligned}$$

where: ** is an exponentiation operator

exp is the base e exponentiation operator

<u>North German Plain Model</u>. The North German Plain regression model was developed in the same general fashion as the Fulda regression model. The same response variable transformation was used. The same functional form for an altitude transformation was used, with the constant in the exponent changed from 200 to 100. Significant interaction terms were delay & RCAMAX and RCAMAX & altitude. The final adjusted R-squared was .97798. The order of importance of all independent variables in the model (as determined by contribution to R-squared) is:

1. Aircraft airspeed
2. SAM system delay
3. RCAMAX
4. Delay & RCAMAX interaction
5. Missile speed
6. RCAMAX & altitude interaction
7. Aircraft altitude

The final regression equation is:

$$\ln((neng/50)/adist = -.416314 + (.227821)[1-\exp(-altitude/100)] - (.146546)(aircraft\ airspeed) - (.0000380024)(rcamax) + (.0309886)(missile\ speed) - (2.68344)(SAM\ system\ delay) + (.0112789)[1/(delay*rcamax/10000)] + (.156470)[(rcamax/10000)/altitude]$$

A summary of the final North German Plain regression model statistical characteristics is contained in Appendix G.

Conclusion

Two methods, factorial design and multiple regression, were used to analyze the results of the terrain-effects simulation model. The outcomes of the factorial analysis were reasonable, and mutually supporting. The two terrain types studied contrasted well. Together they provide valuable insight on how terrain influences the outcome of an aircraft/SAM system encounter. In addition, the corresponding regression equations that were developed have extremely high predictive capability, accounting for almost all of the variance in the response variable.

VI. Summary and Recommendations

Summary

Terrain may often be a decisive factor in real-world encounters between aircraft and surface-to-air missile systems. Although military pilots are thoroughly trained in terrain-masking techniques, military analysts and mission planners have not had a method available to model the effects of different terrain types on the aircraft-SAM system encounter. The only thorough terrain models currently available are site-specific; they model terrain effects experienced by a specific SAM system at a specific location. The objective of this research was to develop a methodology that quantifies the essential characteristics of an entire terrain type in terms of its impact on the aircraft-SAM system encounter.

This research focused as strictly as possible on the role of terrain in the aircraft-SAM system encounter. Larger parent models at such defense agencies as HQ USAF Studies and Analysis already account for many of the other aspects of this encounter, such as the Probability of Successful Missile Launch, Probability of Successful Missile Guidance, and Probability of Accurate Warhead Detonation. This study assigned these probabilities a value of one, so that the output of the terrain effects model can be used as an independent input to these parent models. In addition, only SAM systems which require line-of-sight between the SAM system radar and the target are modeled, because the impact of terrain is most significant on these systems. Finally, the target is assumed to be passive, flying a straight-line flight path through the SAM system's lethal zone without employing any defensive measures on its own behalf. Again, aircraft defensive measures, such as maneuver or electronic

countermeasures, are already incorporated in larger parent models.

General Approach. Two contrasting types of terrain were chosen for analysis, the moderately rugged terrain around Fulda, West Germany, and the extremely flat area near Hamburg, West Germany, generally referred to as the North German Plain. Digitized terrain elevation data (DTED), developed by the Defense Mapping Agency, served as raw data. Twenty suitable SAM sites were chosen in each terrain area as representative samples. Four layers of data transformation were required to convert the DTED data for these sites into terrain models: (1) the DTED data was converted to line-of-sight values; (2) the line-of-sight values were transformed into masked and unmasked distances that an aircraft would fly at a particular altitude; (3) the masked and unmasked distances were sorted into 49-cell data groupings, according to aircraft altitude, position relative to the SAM site, and whether the distance involved was a masked or an unmasked distance; and (4) each cell of the 49-cell models were fit to a probability distribution function, using the AID statistical analysis package. The resulting theoretical distributions of masked and unmasked distances accurately characterized the nature of each terrain type in terms that a model of the aircraft-SAM system encounter could use. These 49-cell groupings of masked and unmasked distance ditributions make up the terrain model. There are separate 49-cell distribution models for masked and unmasked distances at each of six altitudes in the Fulda area, and three altitudes in the North German Plain.

The next step, once the terrain models were completed, was to analyze the effects of each terrain type on the aircraft-SAM system encounter. A simulation model was used to determine the number of

completed engagements an aircraft would experience per nautical mile flown through a battle area in each terrain type. The simulation runs used five key variables: aircraft altitude, aircraft airspeed, threat density (RCAMAX), missile speed, and SAM system reaction time ("delay"). The simulation results were analyzed by two complementary methods, factorial analysis and multiple regression. A full factorial analysis was accomplished to determine what the significant factors were, and how they interacted to define terrain effects on the aircraft-SAM system encounter. Multiple regression was used to develop a single equation that will predict terrain effects, in terms of an upper bound on the number of complete engagements possible, for each terrain type.

Findings

Factorial Analysis. All five factors chosen for analysis were significant in both the Fulda area and the North German Plain, at both the main factor level and at the two-way interaction level. SAM system delay was always the predominant single factor, followed by threat density (RCAMAX). SAM missile speed was always last among the five factors in level of significance. While these SAM system parameters are not controllable factors from an Air Force perspective, the significance of SAM system delays in influencing the number of engagements an aircraft experiences should not be ignored. Any method that an aircraft could employ to extend these delays, by such "confusion" techniques as electronic countermeasures or chaff, could obviously pay important benefits in reducing the number of possible engagements.

The two aircraft parameters, altitude and airspeed, provide notable results. In the North German Plain, where terrain effects are limited, aircraft airspeed is much more important than altitude. In the Fulda

area, where terrain effects have much more impact, the roles of these two factors are reversed: altitude is much more significant than airspeed. Also, the impact of airspeed as a factor is generally linear, particularly in the Fulda area. Faster airspeed results in fewer completed engagements, although the slope of the line connecting observations becomes fairly flat at longer SAM system delays.

The altitude factor is interesting because it indicates where terrain effects begin to occur. For instance, the number of engagements experienced in the North German Plain is almost constant at altitudes of 100 feet AGL and above, so terrain must have a masking effect only for aircraft flying below 100 feet. If flight below 100 feet AGL is not practicable, then there is no particular advantage to low-level flight at all, at least from a terrain-masking point of view. Flight at higher altitude may be safer in that it at least precludes collision with the ground. On the other hand, in the Fulda area, substantial terrain-masking effects are felt up through at least 500 feet AGL, and possibly up to 750 feet AGL in some cases. In this kind of terrain, some benefits will definitely accrue from low-level flight, and generally, the lower the altitude, the better, at least from a terrain-masking perspective.

A second important finding with respect to aircraft altitude is that, as altitude decreases, the number of completed engagements appears to decrease exponentially. The exact parameters of the exponential relationship appear to depend on the terrain type, as shown by the exponential transformations used in the regression equations. One way of classifying terrain types may be according to the parameters of this exponential relationship. In any case, since engagements appear to decrease exponentially, not linearly, with flight at lower altitudes, operational emphasis should continue to stress flying at the lowest

practicable altitude in areas where terrain masking can be achieved.

Multiple Regression. The multiple regression equations (one for each terrain type) represent the ultimate product of this research. Inputting values for aircraft altitude and airspeed, average missile velocity, SAM system response time, and threat density, into these regression equations will produce a predicted value for Engagements per Aircraft per Nautical Mile in that terrain type. This measure can then be used as the "terrain effects" input into a larger parent model. The most significant findings from the multiple regression analysis are, of course, the equations themselves. However, they also identify the actual exponential form of the aircraft altitude parameter. Secondly, their high R-squared values show how well terrain-effects models can be fit to regression equations.

Recommendations for Further Study

This research did not fully investigate all potential approaches to characterizing the effects of terrain on aircraft and SAM system encounters. The progression of analysis leading to final regression models may not be the only way to address this subject. Although most efforts in this area must probably share the DMA digital terrain data base as a common starting point, subsequent courses of analysis may proceed along the same general approach, or use entirely different analytical techniques. Further analysis could involve expansion and/or improvement of the techniques presented in this effort, or address issues that could enhance its applicability.

Analytical Techniques. Simulation (which really is at the heart of the analytical techniques used in this effort) may not be the only way to arrive at an estimation of the number of engagements per aircraft per

nautical mile. Mathematical techniques relying on Central Limit Theorem application to the numerous probability distributions in the 49-cell terrain models may be feasible. If simulation cannot be avoided, the use of such techniques could simplify the terrain model by reducing the number of distributions to be sampled from. It is possible that the terrain model itself could be reduced and modified to a form that could be used as a direct input to another model. For example, one approach anticipated early on during this research effort was regression of the distribution parameters for the 49 cells of the terrain model. A simple regression equation (as opposed to the extensive code in the terrain models) could possibly be effectively and compactly incorporated directly into a larger model. The larger model could conduct simulations using the regression equation to establish the parameters of the needed distributions. This approach was abandoned when it became apparent that any single type of distribution could not be consistently anticipated.

The development and use of multivariate distributions was not attempted in this study, even though some phenomenon modeled were in fact multivariable dependent. For example, the angle and range at which masked or unmasked distances begin, and the length of the distance are are all random variables, with associated probability distributions. This research approximated marginal distributions of distance measures while fixing the values of the other two random variables. The result of this is the 49 cell terrain models in which the continuous variables of angle and range are discretized to form cell boundaries. If multivariable distributions were used, the approximation inherent in using discrete cells would be removed.

Applicability. The applicability of this effort is limited by the

small geographic areas studied. Ideally, specific regions that have not been studied could be analytically "matched" to base case regions which have been characterized along the lines presented. Instead of cataloging large terrain models for each region of interest, measures of similarity to regions which have detailed terrain models compiled could be developed. If a region's terrain corresponded closely to a base case region (through whatever measure or system of measurements developed to establish correspondence), the base case terrain model could be used. If regions did not match well, interpolation between base case types could possibly be used. This would require developing appropriate analytical criteria to establish terrain type similarities to serve along the lines of the familiar subjective "rolling hills", "rugged mountains", and "endless plains" types of verbal terrain characterizations. The "matching" process could be developed and conducted using DMA digital terrain data bases.

Bibliography

1. Anderson, Kenneth C. and Ronald B. Nenner. A Wild Weasel Penetration Model. Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 1983.

2. Banks, Jerry, and John S. Carson, II, Discrete-Event System Simulation. Englewood Cliffs NJ: Prentice-Hall, Inc., 1984.

3. Bruer, D. Wallace. The Fundamentals of Weapons Engineering, Vol I. Textbook for SE 5.81, School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 1984.

4. Burge, C.L. and J.H. Lind. Line-of-Sight Handbook. Naval Weapon Center Report, TP 5908. China Lake, CA, January 1977.

5. Dalkey, Norman C. "Simulation," Systems Analysis and Policy Planning: Applications in Defense, edited by E.S. Quade and W.I. Boucher. New York: Elsevier Scientific Publishing Company, 1977.

6. Defense Mapping Agency, Catalogue of Digital Data. St. Louis: Defense Mapping Agency Aerospace Center, 1982.

7. Defense Mapping Agency, Product Specifications for Digital Landmass System (DLMS) Data Base. Second Edition. St. Louis: Defense Mapping Agency Aerospace Center, April 1983.

8. Defense Mapping Agency, Product Specifications for Digitized Elevation Data for Firefinder. Second Edition. Washington: Hydrographic/Topographic Center, February 1981.

9. Dixon, W. J. et al. BMDP Statistical Software (1983 Edition). Los Angeles: University of California Press, 1983.

10. Ebeling, Lt Col Charles. Class notes from SM 6.66, Military Systems Simulation. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson Air Force Base OH, September 1985.

11. Foley, Michael J. and Stephen G. Gress, Jr. A Simulation Model to Evaluate Aircraft Survivability and Target Damage During Offensive Counterair Operations. Master of Science Thesis, School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 1984.

12. Golden, August, Jr., Radar Electronic Warfare. Textbook for EE 5.73, School of Engineering, Air Force Institiute of Technology (AU), Wright-Patterson AFB OH, May 1983.

13. Green, Paul E., Analuzing Multivariate Data. Hinsdale, IL: The Dryden Press, 1978.

14. Greene, Terrell E. "TACAIR in Defense of NATO," Astronautics and Aeronautics, 15 (3): 18-27 (March 1977).

15. Hines, William W., and Douglas C. Montgomery, Probability and Statistics in Engineering and Management Science. New York: John Wiley & Sons Inc., 1980.

16. Leek, Warren J. and Richard W. Schmitt. Survivability Study of a FLIR Equipped Fighter on a Night Penetration of a Soviet Army. Master of Science Thesis, School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 1981.

17. McKinney, Dana Bruce. A Tactical Aid for Planning Air Strikes Against Radar Defended Land Targets. Master of Science Thesis, Naval Postgraduate School, Monterey, California, September 1983.

18. Might, Lt Col Robert, Chief, Studies and Analysis Directorate for Theater Force Analyses, Fighter Division. Telephone interview. HQ USAF, Washington, D.C., 22 May 1985.

19. Montgomery, Douglas C. Design and Analysis of Experiments. New York: John Wiley & Sons Inc., 1984.

20. Neal, Donald W. and Gary G. Kizer. A Simulation Model to Evaluate Close Air Support Kill-to-Loss Ratios. Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 1983.

21. Pyati, Dr. V. P. Class notes from EE 5.73, Electronic Warfare. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, September 1985.

22. Richart, David K., Analyst, Aeronautical Systems Division, Engineering System Survivability and Effectiveness Branch. Personal interview. Air Force Systems Command, Wright-Patterson AFB OH. 24 April 1985.

23. "Soviets Order SA-8s Into Action In Bekaa After Israeli Successes," Aviation Week and Space Technology, 177: 18-19 (9 August 1982).

24. Specht, R.D. "The Nature of Models," Systems Analysis and Policy Planning: Applications in Defense, edited by E.S. Quade and W.I. Boucher. New York: Elsevier Scientific Publishing Company, 1977.

25. Taylor, John W.R., "Gallery of Soviet Aerospace Weapons," Air Force Magazine, 68: 111-112 (March 1985).

Appendix A. SLAM NETWORK

```
GEN,HAMILTON & JOHNSON,THESIS,8/21/85,288,N,N,Y,N,N;
LIMITS,10,10,500;
INTLC,XX(26)=.2667,XX(7)=0,XX(19)=50;        SET CYCLE
NETWORK;
       RESOURCE/SAM1(1),1;
;
       CREATE,20,0,1;                         IN 20 MINUTE INTERVALS
       ASSIGN,XX(4)=0,XX(1)=0;                 REINITIALIZE
       ACT/6,,,A1;                           CREATE ONE AIRCRAFT
;
A1     ASSIGN,ATRIB(2)=XX(22),ATRIB(3)=XX(23); AIRSPEED(NM/MIN),ALT
;       ASSIGN,XX(24)=XX(24)+1;                  TRACE VARIABLE
;       ASSIGN,ATRIB(5)=XX(24);                  TRACE ATRIB
S1     AWAIT(1),SAM1;
R1     EVENT,1,1;
       ACT/1,XX(6),XX(1).EQ.0,EXIT;           EXIT SAM'S ZONE
       ACT,XX(6),XX(1).NE.0,P1;               STILL IN SAM'S ZONE
;
P1     GOON,1;
       ACT/2,,XX(3).EQ.1,R1;                  STILL FLYING IN SAM
       ACT/3,,XX(3).NE.1,DIE;                 ENGAGED IN EVENT(1)
EXIT   GOON,1;
       ACT/4,0,XX(5).EQ.1,END;                EXIT FEBA
       ACT/5,0,XX(5).NE.1;                    EXIT THIS SAM, GO
       FREE,SAM1;                                TO NEXT SAM
       ACT,,,S1;
;
DIE    FREE,SAM1;
       ASSIGN,XX(20) = XX(20) + 1;              COUNT ENGAGED A/C
       ACT,,,S1;
END    ASSIGN,XX(21) = XX(21) + 1;              COUNT SURVIVORS
       ACT;
       FREE,SAM1;
       TERM;                                    TERM A/C
       ENDNETWORK;
INIT,0,999;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=50,XX(25)=37440;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=50,XX(25)=25926;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=50,XX(25)=14815;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=100,XX(25)=37440;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=100,XX(25)=25926;
SIMULATE;
```

```
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=100,XX(25)=14815;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=250,XX(25)=37440;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=250,XX(25)=25926;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=250,XX(25)=14815;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=500,XX(25)=37440;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=500,XX(25)=25926;
SIMULATE;
SEEDS,0(4),0(5);
INTLC,XX(12)=19,XX(22)=9,XX(23)=500,XX(25)=14815;
SIMULATE;
;
;12 REPS
;
```

.
.
.
.
.
etc

Appendix B. SLAM Discrete Event Code

```
      PROGRAM MAIN
      REAL LEADANG,DELTA,DCRIT,RANGE
      DIMENSION NSET(10000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/SAM1/FACTOR,TIME,DIST2,MSLDIST,CRITTIME,X,LEADANG,DELTA,
     1DCRIT,RANGE
      COMMON QSET(10000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=10000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      CALL SLAM
      STOP
      END


      SUBROUTINE EVENT(I)
      REAL MSLDIST,LEADANG,DELTA,DCRIT,RANGE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/SAM1/FACTOR,TIME,DIST2,MSLDIST,CRITTIME,X,LEADANG,DELTA,
     1DCRIT,RANGE
      GO TO (1,2)I
C     *************  LIST OF GLOBAL VARIABLES  ******************
C         XX(1)  --  CUM DISTANCE TRAVELED ACROSS SAM
C         XX(2)  --  TOTAL CHORD DISTANCE ACROSS SAM
C         XX(3)  --  SURVIVE SAM ENGAGEMENT
C         XX(4)  --  CUMULATIVE DISTANCE TRAVELED ACROSS THREAT AREA
C         XX(5)  --  FLAG FOR SAFE EXIT FROM THREAT AREA
C         XX(6)  --  TIME OF FLIGHT
C         XX(7)  --  MASK/UNMASK CYCLES THROUGH SAM
C         XX(8)  --  RADIUS OF CLOSEST APPROACH TO SAM RADAR (RCA)
C         XX(9)  --  RCA IN NAUTICAL MILES             (RCAINNM)
C         XX(10) --  THETA  -- ENGAGEMENT ANGLE
C         XX(11) --  INITIALLY MASKED/UNMASKED (RANDOM)
C         XX(12) --  MISSILE SPEED
C         XX(13) --  UNMASKED DISTANCE SEGMENT FLOWN
C         XX(14) --  UNMASKED DISTANCE COLLECT STATISTIC
C         XX(15) --  SEED BLOCK COUNTER
C         XX(16) --  MASKED DISTANCE SEGMENT FLOWN
C         XX(17) --  TOTAL SAM DISTANCE FLOWN, INCLUDING OVERFLY
C         XX(18) --  OVERFLY OF SAM DISTANCE FLOWN
C         XX(19) --  THREAT ZONE DISTANCE
C         XX(20) --  ATTRITED AIRCRAFT COUNTER
C         XX(21) --  SURVIVING AIRCRAFT COUNTER
C         XX(22) --  AIRCRAFT AIRSPEED
C         XX(23) --  AIRCRAFT ALTITUDE
C         XX(24) --  TRACE VARIABLE
```

```
C           XX(25) --  MAX RCA / THREAT DENSITY CONTROL
C           XX(26) --  SAM CONFOUNDING DELAY
C
1       FACTOR=.0174533                DEGREE TO RADIAN CONVERSION FACTOR
        XX(7)=XX(7)+1                  # OF ENGAGEMENTS WITH PRESENT SAM
        IF (XX(13).GT.0) THEN
           XX(16)=0                   PREVIOUS ENGAGEMENT COMPLETE PRIOR
           GO TO 60                   TO RUNNING OUT OF UNMASKED DISTANCE
           ENDIF                      REMAINING DISTANCE FLOWN.
        IF (XX(7).GT.1) GO TO 50
        XX(8)=DRAND(5)*XX(25)          ENCOUNTER GEOMETRY INITIALIZATION
        XX(9)=XX(8)*.00054             CODE SKIPPED IF NOT JUST ENTERING
        XX(3)=1                        THREAT AREA OR TRANSITIONING
        XX(5)=0                        BETWEEN SAM SITES.  OTHERWISE,
        XX(10)=ACOS(XX(8)/XX(25))      GEOMETRY INITIALIZED.
        XX(2)=SIN(XX(10))*2*XX(25)*.00054
        XX(11)=USERF(3)
50      IF (XX(11).EQ.1) THEN         UNMASKED OR MASKED CODE ACCESSED,
           XX(16)=0                   DEPENDING ON INITIAL MASKED OR
           GO TO 10                   UNMASKED CONDITION DETERMINATION
           ENDIF
        IF (XX(11).EQ.0) GO TO 20
C
C       **************************************************
C       **                UNMASKED SEGMENT              **
C       **************************************************
C
10      RANGE=XX(8)/COS(XX(10))        SAM-RADAR-TO-AIRCRAFT DISTANCE
        CALL UNMASK                    TERRAIN MODEL UNMASK DISTANCE DRAWN
C
C
        XX(17)=XX(1)+XX(13)            XX(17) MANIPULATIONS ENSURE THAT
        IF (XX(17).GT.XX(2)) THEN      THE AIRCRAFT IS NOT ALLOWED THE
           XX(18)=XX(17)-XX(2)         EXCESS DISTANCE BEYOND WHICH XX(13)
           XX(13)=XX(13)-XX(18)+.2     MIGHT TAKE IT OUT OF SAM RANGE.
           ENDIF                       RESULTS IN CONTINUOUS COVERAGE.
C
C
60      XX(10)=ATAN((XX(2)/2-XX(1)-XX(22)*XX(26))/XX(9)) ENGAGEMENT ANGLE
        LEADANG=ASIN(ATRIB(2)/XX(12)*COS(ABS(XX(10))))  CONSTANT BEARING
C                                                       COURSE LEAD ANGLE
C

              THE FOLLOWING SERIES OF CONDITIONAL STATEMENTS
              COMPUTE A CRITICAL DISTANCE DURING WHICH A COMPLETE
              ENGAGEMENT MAY OCCUR.  THE POSITIVE/NEGATIVE ANGLE
              CONVENTION REQUIRES SEVERAL STATEMENTS TO ENCOMPASS
              ALL POSSIBLE GEOMETRIES FOR WHICH THE COMPUTATIONS
              MAY CONCEIVABLY BE MADE.

        IF (XX(1).LT.XX(2)/2) THEN
           DELTA=XX(10)-LEADANG
           IF (DELTA.LT.0) DCRIT=XX(2)/2-XX(1)+XX(9)*TAN(ABS(DELTA))
           IF (DELTA.GE.0) DCRIT=XX(9)*TAN(XX(10))-XX(9)*TAN(DELTA)
           ENDIF
```

```
      IF (XX(1).GE.XX(2)/2) THEN
         DELTA=ABS(XX(10))+LEADANG
         DCRIT=XX(9)*TAN(DELTA)-ABS(XX(2)/2-XX(1))
         ENDIF
      DCRIT=DCRIT+XX(22)*XX(26)       DCRIT ADJUSTED FOR SAM DELAYS

            SATISFACTION OF THE FOLLOWING IF/THEN STRUCTURE
            OCCURS WHEN THE AIRCRAFT EXITS BOTH THE THREAT AREA
            AND THE PRESENTLY-ENGAGED SAM SYSTEM COVERAGE.  THE
            SIMULATION RUN IS OVER

      IF ((XX(4)+DCRIT).GT.XX(19).AND.(XX(1)+DCRIT).GT.XX(2)) THEN
         XX(7)=0
         XX(18)=0
         XX(3)=1
         XX(14)=XX(13)
         XX(13)=0
         XX(6)=USERF(2)
         XX(1)=0
         XX(17)=0
         XX(5)=1
         RETURN
         ENDIF

         SATISFACTION OF THE FOLLOWING IF/THEN STRUCTURE OCCURS
         WHEN THE AIRCRAFT HAS EXITED A SAM SYSTEM'S COVERAGE,
         BUT NOT THE THREAT AREA IN GENERAL.  GLOBAL VARIABLES
         ARE INITIALIZED TO ENSURE THAT THE AIRCRAFT WILL
         TRANSITION TO AN ENGAGEMENT WITH ANOTHER SAM SYSTEM
         UPON RETURNING TO THE EVENT(1) SUBROUTINE FROM THE
         SLAM NETWORK.

      IF ((XX(1)+DCRIT).GT.XX(2)) THEN
         XX(7)=0
         XX(18)=0
         XX(3)=1
         XX(4)=XX(4)+XX(13)
         XX(14)=XX(13)
         XX(13)=0
         XX(6)=USERF(2)
         XX(1)=0
         XX(17)=0
         RETURN
         ENDIF

         THE FOLLOWING IF/THEN STRUCTURE IS FOR THE CASE WHERE
         THE COMPUTED UNMASKED DISTANCE IS GREATER THAN THE
         DISTANCE REQUIRED TO INTERCEPT THE AIRCRAFT.

      IF (XX(13).GE.DCRIT)THEN
         XX(3)=0
         XX(1)=XX(1)+DCRIT
         XX(4)=XX(4)+DCRIT
         XX(13)=XX(13)-DCRIT
         XX(14)=XX(13)
```

```
         XX(6)=(DCRIT+XX(16))/ATRIB(2)
         XX(10)=ATAN((XX(2)/2-XX(1))/XX(9))
         RETURN
         ENDIF
      XX(1)=XX(1)+XX(13)     IF NO SHOOT-DOWN OCCURS, AND THE AIRCRAFT
      XX(4)=XX(4)+XX(13)     REMAINS WITHIN SAM SYSTEM COVERAGE, DISTANCE
      XX(6)=USERF(2)         TRAVELED IS UPDATED, TIME COMPUTED, AIRCRAFT
      XX(14)=XX(13)          SURVIVAL FLAG IS SET, SUBSEQUENT ENTRY INTO
      XX(13)=0               EVENT(1) SET TO START WITH A MASKED DISTANCE
      XX(3)=1                COMPUTATION, AND NEXT ENGAGEMENT START ANGLE
      XX(11)=0               COMPUTED
      XX(10)=ATAN((XX(2)/2-XX(1))/XX(9))
      RETURN
C
C
C
C     ***************************************************
C     **                 MASKED SEGMENT                **
C     ***************************************************
C
20    RANGE=XX(8)/COS(XX(10))          THE MASKED CODE PARALLELS THE
      CALL MASK                        UNMASKED CODE, EXCEPT THAT NO
C                                      CRITICAL DISTANCE COMPUTATIONS
C                                      ARE MADE.  THE GEOMETRY FOR THE
C                                      UPCOMING EXPOSURE IS SIMPLY
      XX(17)=XX(1)+XX(16)              UPDATED BY THE CONTRIBUTION OF A
      IF (XX(17).GT.XX(2)) THEN        RANDOMLY DRAWN MASKED DISTANCE.
         XX(18)=XX(17)-XX(2)           THE SAME CHECKS AS TO WHETHER THE
         XX(16)=XX(16)-XX(18)+.2       AIRCRAFT HAS EXITED THE THREAT AREA
         ENDIF                         OR SAM SYSTEM COVERAGE ARE MADE.
      XX(1)=XX(1)+XX(16)
      XX(4)=XX(4)+XX(16)
      IF (XX(4).GT.XX(19) .AND. XX(1).GT.XX(2)) THEN
         XX(7)=0
         XX(18)=0
         XX(13)=0
         XX(6)=USERF(2)
         XX(1)=0
         XX(3)=1
         XX(17)=0
         XX(5)=1
         RETURN
         ENDIF
      IF (XX(1).GT.XX(2)) THEN
         XX(7)=0
         XX(18)=0
         XX(3)=1
         XX(13)=0
         XX(6)=USERF(2)
         XX(1)=0
         XX(17)=0
         RETURN
         ENDIF

          IF OUTSIDE SAM LETHAL RADIUS, SET UP FOR NEXT SAM/AC
```

```
            ENCOUNTER AND RETURN TO NETWORK

      XX(10)=ATAN((XX(2)/2-XX(1))/XX(9))
      GO TO 10

      GOES DIRECTLY TO UNMASKED PORTION OF CODE TO EVALUATE NEXT
      EXPOSURE FOR THIS AIRCRAFT/SAM SYSTEM COMBINATION.
C
C           *************  END OF EVENT(1)  ****************
C
      RETURN
      END
C
C
      SUBROUTINE INTLC
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      RETURN
      END
C
C
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      AVED=CCAVG(2)
      WRITE(99,110)XX(23),XX(22),AVED,PS,XX(20),XX(25),XX(12),
     1XX(26)
110   FORMAT(1X,F5.0,4X,F5.0,4X,F7.2,4X,F6.4,4X,F5.0,4X,F6.0
     1,4X,F5.1,4X,F7.4)
      RETURN
      END
C
C
      FUNCTION USERF(IFN)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      GO TO (1,2,3) IFN
1     USERF = XX(13)/ATRIB(2)
      RETURN
2     USERF = (XX(13)+XX(16))/ATRIB(2)
      RETURN
C
C     ******* DETERMINE WHETHER INITIALLY MASKED/UNMASKED ***********
3     X=DRAND(5)

         INITIAL MASKED/UNMASKED CONDITION IS DETERMINED BY
         TAKING THE RATIO OF UNMASKED READINGS TO THE TOTAL
         NUMBER OF READINGS FOR THE THREE OUTERMOST DATA CELLS
         IN THE LEFT HALF OF THE 49 CELL TERRAIN MODEL.  IF THE
         RANDOM NUMBER DRAW IS LESS THAN OR EQUAL TO THIS RATIO,
         AN UNMASKED CONDITION IS SPECIFIED.  OTHERWISE, A
         MASKED CONDITION IS SPECIFIED.  THE FOLLOWING CODE
         WAS USED FOR THE NORTH GERMAN PLAIN MODEL.

C      *************** ALT = 50 FEET ***************
```

```
      IF (XX(23).EQ.50) THEN
         IF (XX(8).LE.18720) THEN
           IF (X.LE..69) N=1
           IF (X.GT..69) N=0
           ENDIF
         IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
           IF (X.LE..59) N=1
           IF (X.GT..59) N=0
           ENDIF
         IF (XX(8).GT.32424) THEN
           IF (X.LE..54) N=1
           IF (X.GT..54) N=0
           ENDIF
         ENDIF
C      **************** ALT = 100 FEET ****************
      IF (XX(23).EQ.100) THEN
         IF (XX(8).LE.18720) THEN
           IF (X.LE..75) N=1
           IF (X.GT..75) N=0
           ENDIF
         IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
           IF (X.LE..6) N=1
           IF (X.GT..6) N=0
           ENDIF
         IF (XX(8).GT.32424) THEN
           IF (X.LE..55) N=1
           IF (X.GT..55) N=0
           ENDIF
         ENDIF
C      **************** ALT = 250 FEET ****************
      IF (XX(23).EQ.250) THEN
         IF (XX(8).LE.18720) THEN
           IF (X.LE..93) N=1
           IF (X.GT..93) N=0
           ENDIF
         IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
           IF (X.LE..52) N=1
           IF (X.GT..52) N=0
           ENDIF
         IF (XX(8).GT.32424) THEN
           IF (X.LE..46) N=1
           IF (X.GT..46) N=0
           ENDIF
         ENDIF

         THE FOLLOWING CODE WAS THE USERF(3) USED FOR
         THE FULDA TERRAIN MODEL
C
C     ******* DETERMINE WHETHER INITIALLY MASKED/UNMASKED ***********
3     X=DRAND(5)
C      **************** ALT = 50 FEET ****************
      IF (XX(23).EQ.50) THEN
         IF (XX(8).LE.18720) THEN
           IF (X.LE..64) N=1
           IF (X.GT..64) N=0
```

```
            ENDIF
          IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
            IF (X.LE..50) N=1
            IF (X.GT..50) N=0
            ENDIF
          IF (XX(8).GT.32424) THEN
            IF (X.LE..503) N=1
            IF (X.GT..503) N=0
            ENDIF
          ENDIF
C        **************** ALT = 100 FEET ****************
        IF (XX(23).EQ.100) THEN
          IF (XX(8).LE.18720) THEN
            IF (X.LE..622) N=1
            IF (X.GT..622) N=0
            ENDIF
          IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
            IF (X.LE..508) N=1
            IF (X.GT..508) N=0
            ENDIF
          IF (XX(8).GT.32424) THEN
            IF (X.LE..506) N=1
            IF (X.GT..506) N=0
            ENDIF
          ENDIF
C        **************** ALT = 250 FEET ****************
        IF (XX(23).EQ.250) THEN
          IF (XX(8).LE.18720) THEN
            IF (X.LE..649) N=1
            IF (X.GT..649) N=0
            ENDIF
          IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
            IF (X.LE..498) N=1
            IF (X.GT..498) N=0
            ENDIF
          IF (XX(8).GT.32424) THEN
            IF (X.LE..523) N=1
            IF (X.GT..523) N=0
            ENDIF
          ENDIF
C        **************** ALT = 500 FEET ****************
        IF (XX(23).EQ.500) THEN
          IF (XX(8).LE.18720) THEN
            IF (X.LE..623) N=1
            IF (X.GT..623) N=0
            ENDIF
          IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
            IF (X.LE..519) N=1
            IF (X.GT..519) N=0
            ENDIF
          IF (XX(8).GT.32424) THEN
            IF (X.LE..522) N=1
            IF (X.GT..522) N=0
            ENDIF
          ENDIF
```

AD-A172 449 TERRAIN-MODELING METHODOLOGY FOR AIRCRAFT ENCOUNTERS WITH SURFACE-TO-AIR..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. 2/2

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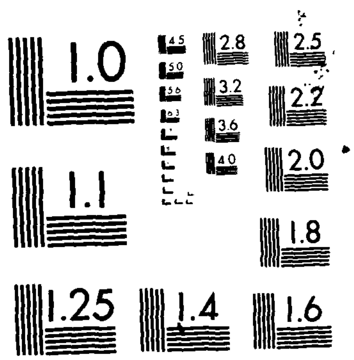

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
C        **************** ALT = 750 FEET ****************
         IF (XX(23).EQ.750) THEN
            IF (XX(8).LE.18720) THEN
              IF (X.LE..675) N=1
              IF (X.GT..675) N=0
              ENDIF
            IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
              IF (X.LE..584) N=1
              IF (X.GT..584) N=0
              ENDIF
            IF (XX(8).GT.32424) THEN
              IF (X.LE..508) N=1
              IF (X.GT..508) N=0
              ENDIF
            ENDIF
C        **************** ALT = 1000 FEET ****************
         IF (XX(23).EQ.1000) THEN
            IF (XX(8).LE.18720) THEN
              IF (X.LE..733) N=1
              IF (X.GT..733) N=0
              ENDIF
            IF ((XX(8).GT.18720).AND.(XX(8).LE.32424)) THEN
              IF (X.LE..577) N=1
              IF (X.GT..577) N=0
              ENDIF
            IF (XX(8).GT.32424) THEN
              IF (X.LE..506) N=1
              IF (X.GT..506) N=0
              ENDIF
            ENDIF
         USERF = N
         RETURN
            END
```

Appendix C. Terrain Models

The following sample of FORTRAN code is typical of that used throughout the terrain models. The variables in this code are set in either the SLAM network or the discrete event subroutine EVENT(1). When the terrain model is called in the discrete event subroutine, a search of the terrain model code is made until the correct combination of variables is located. Aircraft altitude is first matched to its pre-determined value with the ATRIB(3) IF/THEN structure. Next, the SAM radar-to-aircraft range is matched with the RANGE IF/THEN structure. Finally, the angle between the RCA line and the radar-to-aircraft line-of-sight line is matched with the appropriate XX(10) IF/THEN structure.

There are two types of XX(10) IF/THEN structures. The first is for data cells that were successfully fitted with a theoretical probability distribution (alpha level of .1). The second is for data cells that had to be split up in order to fit theoretical distributions. After split-up, the resulting subsets of the original data were weighted by the number of data points in the subset divided by the overall number of data points in the cell. The subset distribution selection is determined by a random draw (X=DRAND(4)). One of each type of XX(10) IF/THEN structure is highlighted.

```
      SUBROUTINE UNMASK
      REAL LEADANG,DELTA,DCRIT,RANGE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/SAM1/FACTOR,TIME,DIST2,MSLDIST,CRITTIME,X,LEADANG,DELTA,
     1DCRIT,RANGE
C
C 1000 FEET
       IF (ATRIB(3).EQ.1000) THEN
       IF (RANGE.GT.34312.39) THEN

    Cell data successfully fitted with probability distribution.
*****************************************************************
*         IF (XX(10).LE.90*FACTOR.AND.XX(10).GE.60*FACTOR)      *
*   1         XX(13)=BETA(.6888,.8734,4)*44.36+.71              *
*****************************************************************
          IF (XX(10).LT. 60*FACTOR.AND.XX(10).GE. 30*FACTOR)
    1         XX(13)=BETA(.3874,1.601,4)*38.69+.39

       Cell data split and two probability distributions fit.
*****************************************************************
*         IF (XX(10).LT. 30*FACTOR.AND.XX(10).GE.0) THEN        *
*             X=DRAND(4)                                        *
*             IF (X.LE..6179775) THEN                           *
*             XX(13)=RLOGN(1.266,1.12,4)                        *
*             ELSE                                              *
*             XX(13)=BETA(.3785,.7041,4)*24.87+5.13             *
*             ENDIF                                             *
*         ENDIF                                                 *
*****************************************************************
          IF (XX(10).LT.0.AND.XX(10).GE.-30*FACTOR) THEN
```

```
         X=DRAND(4)
         IF (X.LE..6531532) THEN
         XX(13)=BETA(.5004,1.427,4)*3.41+.33
         ELSE
         XX(13)=BETA(.4272,.5921,4)*23.05+4.88
         ENDIF
      ENDIF
      IF (XX(10).LT.-30*FACTOR.AND.XX(10).GE.-60*FACTOR)
     1   XX(13) =RLOGN(4.107,7.394,4)
      IF (XX(10).LT.-60*FACTOR.AND.XX(10).GE.-90*FACTOR)
     1   XX(13) =BETA(.2988,.4626,4)*12.11+.72
    ENDIF
C
    IF (RANGE.GT.31828.61.AND.RANGE.LE.34312.39) THEN
      IF (XX(10).LE.90*FACTOR.AND.XX(10).GE.60*FACTOR)
     1   XX(13) =BETA(.426,.5758,4)*43.87+.64
      IF (XX(10).LT.60*FACTOR.AND.XX(10).GE.30*FACTOR)
     1   XX(13) =BETA(.3117,.9975,4)*35.79+.35
                            .
                            .
                            .
                            .
                           etc
```

BETA random variates were generated using:

distance=BETA(alpha,beta,IS)*(maximum data value - minimum data value) + minimum data value

LOG NORMAL random variates were generated using:

distance=RLOGN(sample mean,sample standard deviation,IS)

NORMAL random variates were generated using:

distance=RNORM(sample mean,sample standard deviation,IS)

GAMMA random variates were generated using:

distance=GAMA(beta,alpha,IS)

WEIBULL random variates were generated using:

distance=WEIBL(beta,alpha,IS)

RNORM, RLOGN, GAMA, BETA, AND WEIBL are all SLAM simulation language function calls. IS is a specification for the random number stream within SLAM to be used in generating the random sample.

The following formats are used in the attached distribution listings:

NORMAL:	N(sample mean,sample standard deviation)
LOG NORMAL:	LN(sample mean,sample standard deviation)
GAMMA:	G(alpha,beta)
BETA:	B(min value,max value,alpha,beta)
WEIBULL:	W(alpha,beta)

The "Cell" heading in the attached distribution listings refers to the data cell of the 49 cell terrain model, as shown in Figure 1. The "Entries" heading refers to the number of data points recorded in that cell. The "Split" heading is used in cases where the data for that cell was split up and the resulting data subsets matched with theoretical distributions. The number preceding the "/" is the distance (in nautical miles) at which the data was divided. The number after the "/" is the number of data points in the data subset with values less than or equal to the number prior to the "/".

For example, the first two entries for FULDA: 50 FEET UNMASKED are:

Cell	Entries	Split	Distribution(s)
1	188		LN(2.348,1.853)
2	252	1.595/195	B(.38,1.58,.6913,1.337), LN(2.665,1.269)

Cell 1 is defined as that area bounded in range by 34312 meters and 37440 meters, and in angle by 90 degrees to 60 degrees. There were 188 data points recorded in this cell. This data was successfully fitted to a Log Normal distribution using an alpha level of .1.

Cell 2 is defined as that area bounded in range by 34312 meters and 37440 meters, and in angle by 60 degrees to 30 degrees. It is adjacent to Cell 1. The 252 data values recorded for this cell could not be fitted (at an alpha level of .1) with any distribution. The data for the cell was split up, with 1.595 nautical miles used as the cut-off point between the two resulting data subsets. Of the 252 data values in the original data set, 195 data values were less than or equal to 1.595 nautical miles. The two data subsets were fit to Beta and Log Normal distributions respectively. After data for a cell was split, the distributions producing the best Kolmogorov-Smirnov goodness-of-fit test statistic were selected. Although data subsets were generally fit successfully with an alpha level of .1, there were exceptions.

The software package used to fit distributions (AID) referred to the goodness-of-fit test as a Kolmogorov-Smirnov test. The authors assumed that the test was in actuality based on sample parameters, rather than population parameters. Therefore, although "Kolmogorov-Smirnov" was the terminology used in the software, it was assumed that a test such as the Lillefors test was used.

FULDA: 50 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	188		LN(2.348,1.853)
2	252	1.595/195	B(.38,1.58,.6913,1.337), LN(2.665,1.269)
3	277	.9878/175	B(.33,.98,.258,.9279), B(.99,6.25,.3197,1.858)
4	301	2.000/273	B(.33,2,.4583,1.121), LN(3.429,1.934)
5	205		LN(1.361,1.284)
6	121		LN(2.494,2.103)
7	144	2.000/105	B(.59,1.99,.49,.7753), LN(4.113,1.977)
8	203	1.100/136	B(.35,1.09,.4419,.7845), LN(2.41,1.23)
9	244	1.000/173	B(.3,1.0,.3301,.7281), LN(2.415,1.315)
10	226		LN(.951,.8199)
11	188	2.000/148	B(.36,1.99,.4498,1.258), LN(4.339,2.668)
12	109		LN(1.733,1.097)
13	102		LN(1.843,1.626)
14	232	1.314/169	B(.32,1.31,.4706,1.123), B(1.34,8.27,.4934,1.707)
15	246	1.009/168	B(.28,.97,.3481,.6781), B(1.11,;6.11,.4396,1.478)
16	280	.9067/162	B(.28,.9,.4016,.8901), B(.91,5.92,.7747,3.314)
17	181	2.000/155	B(.32,1.93,.4763,1.307), LN(4.869,3.237)
18	100		LN(1.745,1.179)
19	239		LN(2.738,2.779)
20	285	.9633/182	B(.29,.96,.5592,.8519), B(.97,6.35,.6414,1.523)
21	286	.9822/179	B(.25,.9,.3221,.7911), LN(2.255,1.153)
22	303	1.989/250	B(.25,1.95,.5078,1.615), LN(3.488,1.553)
23	252	1.665/195	B(.29,1.66,.4881,1.118), LN(3.061,1.309)
24	158	2.290/92	B(.54,2.26,.5635,1.19), LN(5.559,3.472)
25	160		LN(2.149,2.035)
26	283	1.203/171	B(.25,1.2,.5484,1.103), LN(2.361,1.172)
27	348	1.100/242	B(.22,1.09,.4451,.9717), LN(2.371,1.229)
28	347	1.137/249	B(.22,1.13,.5656,1.104), LN(1.982,.7707)
29	308	1.716/238	B(.26,1.68,.5604,1.191), LN(2.828,1.065)
30	203	2.639/147	LN(1.193,1.072), B(2.65,17.75,.4481,1.329)
31	207		LN(1.813,1.742)
32	394		LN(1.087,1.057)
33	414	.9667/271	B(.18,.96,.4811,.9697), B(.97,7.26,.6839,3.221)
34	402	.9878/259	B(.18,.97,.4914,1.004), B(.99,7.45,.8721,4.28)
35	308	2.000/253	B(.22,1.97,.5234,1.43), LN(4.108,2.453)
36	190	2.703/126	B(.39,2.6,.6263,1.544), B(2.73,18.89,.5217,1.498)
37	324		LN(1.603,1.439)
38	420		LN(1.1,1.212)
39	557	.8830/323	B(.13,.88,.5848,1.091),LN(1.957,1.107)
40	507	1.500/398	B(.13,1.5,.6856,1.293), LN(2.757,1.12)
41	409		LN(1.067,1.168)
42	229	2.500/186	B(.29,2.47,.7583,1.378), B(2.58,22.28,.2179,.4692)
43	448		LN(1.964,2.454)
44	613		LN(1.253,1.715)
45	694		LN(1.272,1.941)
46	634		LN(1.16,1.712)
47	551		G(1.146,1.198)
48	355		LN(2.204,2.767)
49	605	2.500/483	B(.01,2.48,.6018,1.314), LN(4.483,2.05)

FULDA: 50 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	105		LN(4.351,5.100)
2	252		LN(4.627,8.321)
3	274	10.22/225	B(.33,10.22,.3629,1.821), W(24.46,3.42)
4	312	6.85/235	B(.33,6.85,.3051,1.368), B(6.86,29.67,.9881,.6467)
5	202		LN(6.447,13.74)
6	154		B(.72,13.24,.3505,.3924)
7	159		LN(4.376,5.495)
8	218		LN(3.98,6.574)
9	243	11.33/207	LN(1.909,2.716), B(11.34,29.7,1.051,.8017)
10	248	11.32/178	LN(1.969,2.654), W(25.9,5.775)
11	177		LN(6.61,14.45)
12	141	11.0/81	LN(2.989,2.854), LN(12.76,.5702)
13	106		LN(4.079,5.142)
14	222		LN(3.018,4.612)
15	243		LN(6.062,17.66)
16	291	13.36/244	LN(2.111,3.431), W(25.2,6.648)
17	227		LN(6.862,16.25)
18	83		B(.6,15.5,.244,.2921)
19	239		B(.51,29.47,.3023,.5973)
20	271		LN(3.536,5.905)
21	280	10.17/234	LN(1.712,2.424), B(10.17,30.0,.291,.2512)
22	292		LN(5.715,16.7)
23	267	12.74/203	LN(2.152,3.064), LN(19.66,1.666)
24	219	11.04/119	LN(2.991,2.852), B(11.05,17.34,.1964,.7334)
25	146		LN(3.576,4.56)
26	244		LN(3.018,5.18)
27	363	10.15/322	B(.22,10.15,.2955,1.173),B(10.15,30.0,.2555,.3082)
28	348	13.36/67	B(.22,13.36,.3406,2.615), W(25.55,6.729)
29	278	13.03/204	LN(1.557,2.058), W(21.38,16.6)
30	162	13.90/115	LN(2.665,2.748), LN(17.29,.6017)
31	209		LN(2.795,3.129)
32	372		LN(2.53,4.077)
33	420	10.12/381	LN(2.076,3.568), B(10.12,30.0,.3173,.2713)
34	441	3.308/295	B(.18,3.308,.4629,1.134), B(3.309,28.33,.369,.3395)
35	330	16.50/268	LN(2.58,4.33), W(22.67,19.7)
36	191	13.11/138	LN(2.945,3.521), W(19.63,30.23)
37	263		LN(2.437,2.843)
38	425		LN(2.43,4.143)
39	522		LN(2.91,7.021)
40	531		LN(3.788,10.36)
41	472	2.989/297	LN(.9023,.7768), B(2.899,25.62,.3817,.3482)
42	321	13.01/248	LN(2.847,3.3), W(21.99, 24.32)
43	379		LN(1.856,2.36)
44	550		LN(1.581,2.409)
45	639		LN(2.04,4.822)
46	638		LN(3.302,11.09)
47	593	2.884/457	LN(.8443,.9088), B(2.885,28.3,.2817,.3292)
48	392	3.15/246	LN(.9547,.8073), B(3.16,27.23,.4485,.3417)
49	627		LN(2.559,10.74)

FULDA: 100 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	211		LN(2.852,2.427)
2	278	1.568/191	B(.39,1.53,.6126,1.03), LN(3.051,1.726)
3	287	2.122/249	B(.33,2.11,.419,1.045), LN(3.859,2.12)
4	304	1.500/224	B(.33,1.49,.4794,.9642), LN(3.236,2.212)
5	221	2.500/189	B(.39,2.34,.466,1.346), LN(4.513,2.068)
6	127		LN(2.985,2.768)
7	43		LN(2.944,2.829)
8	218		LN(1.41,1.242)
9	240	1.430/159	B(.3,1.35,.556,1.067), B(1.51,9.34,.4145,1.64)
10	218	1.500/171	B(.3,1.5,.5044,1.065), LN(3.13,2.041)
11	203	2.199/146	B(.36,2.19,.441,1.127), LN(4.864,2.98)
12	110		LN(2.481,2.131)
13	113		LN(2.511,2.312)
14	259	1.500/178	B(.32,1.5,.3913,.944), B(1.52,12.57,.4479,1.537)
15	265	1.574/194	B(.28,1.52,.4508,1.004), B(1.6,10.63,.4523,1.882)
16	278	1.357/184	B(.28,1.35,.4354,.9131), B(1.42,9.97,.6124,3.041)
17	170	2.000/133	B(.33,1.97,.5633,1.337), LN(5.058,3.659)
18	101		LN(2.187,1.736)
19	232		LN(3.208,3.454)
20	286	1.592/204	B(.29,1.58,.7856,1.487), B(1.62,12.01,.3229,1/134
21	290	1.882/221	B(.25,1.83,.4841,1.49), B(1.92,14.94,.5364,2.521)
22	349	2.002/265	B(.25,1.93,.5258,1.429), LN(3.888,1.879)
23	228	2.000/177	B(.29,2.0,.5462,1.237), LN(4.339,2.387)
24	171		LN(3.122,3.316)
25	164		LN(2.319,2.263)
26	302	1.414/196	B(.25,1.41,.6408,1.206), LN(2.958,1.632)
27	323	1.436/249	B(.22,1.43,.4929,1.051), LN(3.445,2.145)
28	373	1.137/233	B(.22,1.13,.5269,1.026), LN(2.296,1.145)
29	320		LN(1.561,1.779)
30	208	2.639/142	B(.48,2.61,.6675,1.218), LN(6.564,3.947)
31	240		LN(2.652,3.234)
32	392		LN(1.412,1.568)
33	398	1.508/288	B(.18,1.49,.453,1.091), B(1.51,12.13,.5208,2.439)
34	420	1.160/275	B(.18,1.16,.6432,1.244), B(1.19,9.0,.8845,3.693)
35	310	2.432/253	B(.21,2.38,.4956,1.427), LN(5.037,3.124)
36	187		LN(2.813,3.676)
37	303		LN(2.086,2.065)
38	423		LN(1.492,1.869)
39	557	1.270/366	B(.13,1.27,.5716,1.096), B(1.28,11.53,.5549,2.954)
40	514		LN(1.487,2.284)
41	395		LN(1.292,1.526)
42	204	2.500/140	B(.29,2.47,.9792,1.226), LN(4.215,2.407)
43	412		LN(2.465,3.092)
44	565		LN(1.77,2.797)
45	624		LN(1.973,3.579)
46	557		LN(1.638,2.751)
47	448	2.127/288	B(.07,2.12,.695,1.124), LN(3.864,1.51)
48	280		LN(3.285,5.026)
49	492	3.268/373	B(.01,3.23,.5011,.9754), LN(6.93,3.789)

FULDA: 100 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	128		LN(3.922,4.728)
2	269		LN(4.221,7.157)
3	280	3.627/195	B(.33,.3.627,.3688,.8967),B(3.628,30.0,.3254,.4012)
4	314	3.482/205	B(.33,3.482,.3841,1.082), B(3.483,28.7,.3604,.406)
5	227	10.41/169	B(.39,10.41,.3475,1.289), W(17.4,9.339)
6	162	8.545/85	LN(2.571,2.034), LN(11.46,.7775)
7	161		LN(4.042,4.706)
8	245		LN(3.458,4.964)
9	221	3.975/147	B(.3,3.975,.3469,1.217), B(3.976,29.7,.3766,.7082)
10	255	11.32/180	LN(1.964,2.508), W(25.0,5.524)
11	186		LN(5.925,13.09)
12	142	8.866/87	LN(2.386,1.877), W(12.9,19.06)
13	104		LN(3.775,4.631)
14	233		LN(2.705,3.905)
15	266	3.582/180	B(.28,3.582,.4115,1.313), LN(13.59,10.77)
16	285	3.52/189	B(.28,3.52,.3082,1.116), B(3.53,29.44,.4899,.6767)
17	234		LN(6.655,14.72)
18	96		B(.62,15.52,.2669,.3789)
19	243	18.57/167	LN(3.47,3.865), LN(23.71,2.638)
20	262		LN(3.73,6.051)
21	298	3.556/206	B(.25,3.556,.3729,1.177), LN(13.52,10.58)
22	326	3.494/248	LN(1.053,.9611), B(3.495,29.45,.4435,.3953)
23	266	12.74/195	LN(2.417,3.665), LN(19.77,1.701)
24	231	11.04/126	LN(2.475,2.175), B(11.05,17.34,.1995,.5891)
25	159		LN(3.365,3.707)
26	252		LN(2.379,3.798)
27	353		LN(4.131,9.663)
28	362	3.481/262	B(.22,3.481,.4652,1.876),B(3.482,29.57,.5086,.4348)
29	287	15.53/212	LN(1.726,2.516), W(21.21,19.49)
30	177	12.01/121	LN(2.378,2.376), W(17.51,21.11)
31	210		LN(2.762,2.977)
32	366		LN(2.225,3.156)
33	400		LN(3.325,7.404)
34	470		LN(5.286,16.79)
35	340	2.872/203	LN(1.003,.8635), B(2.873,24.17,.3991,.3978)
36	209	2.934/100	LN(1.408,.8106), B(2.935,20.74,.2609,.2514)
37	240		LN(2.216,2.421)
38	411		LN(2.071,3.145)
39	524		LN(2.478,5.409)
40	527		LN(3.51,10.12)
41	473	2.989/295	LN(.8393,,.7234), B(2.990,25.6,.33,.3536)
42	300	2.858/169	LN(1.386,.9398), B(2.859,23.4,.2436,.2595)
43	344		LN(1.73,2.209)
44	517		LN(1.382,2.043)
45	576		LN(1.725,3.58)
46	555		LN(3.333,10.56)
47	484		LN(3.421,10.08)
48	333	12.12/249	LN(2.081,3.134), B(12.13,27.1,2.026,.678)
49	496		LN(2.686,11.42)

FULDA: 250 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	196		LN(5.414,5.669)
2	263	3.750/193	B(.38,3.64,.6373,1.287), LN(8.394,4.814)
3	291	1.611/164	B(.33,1.46,.4561,.7538), LN(3.522,1.685)
4	314	3.156/267	B(.33,3.13,.4743,1.161), B(3.19,25.76,.2422,.665)
5	298	1.773/201	B(.35,1.76,.648,1.455), LN(4.418,2.894)
6	128		LN(4.268,4.889)
7	138		LN(5.258,7.421)
8	233	3.764/173	B(.35,3.72,.5973,1.537), B(3.79,27.66,.4015,.9893)
9	263	2.434/187	B(.3,2.42,.4378,1.086), LN(4.517,2.161)
10	236	3.560/209	B(.3,3.5,.3601,1.106), LN(9.046,6.468)
11	226	1.845/145	B(.36,1.57,.5492,.9879), B(1.86,12.24,.2464,.7412)
12	108		LN(4.357,5.15)
13	114		LN(3.142,3.071)
14	256	3.504/192	B(.32,3.3,.5367,1.236), B(3.53,25.79,.4342,.8687)
15	261	2.269/185	B(.28,2.23,.3439,.928), B(2.32,16.19,.4756,2.121)
16	272	3.232/215	B(.28,3.14,.432,1.204), LN(8.909,6.455)
17	215	2.569/169	B(.32,2.54,.5196,1.348), B(2.71,18.31,.58,1.542)
18	89		LN(4.214,4.482)
19	138		LN(5.258,7.421)
20	269		LN(2.953,4.302)
21	259	2.940/211	B(.25,2.89,.506,1.391), B(2.98,21.77,.3499,1.611)
22	316	2.301/217	B(.25,2.28,.5051,1.138), LN(5.372,2.975)
23	267	2.557/208	B(.3,2.49,.5902,1.757), LN(6.483,3.495)
24	152		LN(4.822,6.479)
25	177		LN(4.38,5.982)
26	298		LN(2.917,4.752)
27	303		LN(1.874,2.692)
28	351	3.027/267	B(.22,3.01,.5002,1.109), LN(6.607,3.86)
29	296	2.609/224	B(.27,2.54,.5486,1.273), LN(5.502,2.772)
30	148		LN(3.828,4.775)
31	208		LN(5.698,9.048)
32	350		LN(2.227,3.013)
33	424	2.144/311	B(.18,2.13,.6068,1.327), LN(5.025,3.229)
34	341	3.201/251	B(.18,3.1,.5576,1.258), LN(6.025,2.762)
35	270		LN(2.173,3.156)
36	199		LN(4.58,6.426)
37	242		LN(4.728,6.856)
38	326		LN(2.861,5.081)
39	442	2.374/297	B(.13,2.37,.6481,1.317), B(2.38,20.33,.4296,1.879)
40	364		LN(3.238,6.236)
41	307		LN(2.411,4.031)
42	140		LN(4.974,8.963)
43	283		LN(5.37,7.934)
44	401	3.470/246	B(.06,3.45,.6392,1.148), B(3.49,30.75,.4637,2.231)
45	465	3.460/300	B(.05,3.37,.5529,1.069), B(3.52,30.74,.5663,2.452)
46	351		LN(3.95,9.253)
47	268		LN(3.488,7.046)
48	163		LN(7.316,15.73)
49	282		LN(11.45,63.25)

FULDA: 250 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	105		LN(3.499,3.959)
2	268	2.306/171	LN(1.04,.59), LN(7.39,4.452)
3	265	4.039/190	B(.33,4.039,.3492,.8774), LN(13.87,11.42)
4	335	3.443/226	B(.33,3.443,.4619,1.587),B(3.444,28.35,.4165,.3942)
5	270	4.843/194	B(.39,4.843,.5083,1.532), W(15.29,3.493)
6	174	10.11/85	LN(2.558,2.158), LN(11.6,.7039)
7	129		LN(3.457,3.946)
8	244		LN(2.771,4.203)
9	250	4.013/182	B(.3,4.013,.3551,1.037), LN(14.07,11.09)
10	301	3.566/203	B(.30,3.566,.5167,1.528),B(3.567,29.69,.5983,.5256)
11	225	8.130/174	LN(1.712,1.699), W(18.13,7.29)
12	123	4.637/73	LN(1.763,1.049), B(4.638,14.63,2.516,.9512)
13	99		LN(3.053, 3.651)
14	236		LN(2. 816,4.608)
15	259	3.995/188	B(.28,3.995,.3804,1.19), LN(12.67,9.492)
16	273	3.550/183	B(.28,3.55,.3576,1.007),B(5.57,29.71,.4153,.4097)
17	284	14.00/216	LN(2.259,2.864), LN(18.41,1.578)
18	100	7.033/70	LN(1.811,1.277), W(14.9,15.33)
19	217	18.53/145	LN(2.543,1.989), LN(22.95,2.557)
20	232		LN(3.36,5.617)
21	282		LN(3.912,9.202)
22	311	6.803/249	B(.25,6.803,.2708,1.335), W(24.89,3.779)
23	312	2.757/170	LN(.8928,.6416), B(2.758,22.41,.5432,.5184)
24	222	13.12/132	LN(2.798,2.598), B(13.13,17.31,.2954,.7439)
25	144		LN(2.198,2.991)
26	250		LN(2.095,3.13)
27	310		LN(3.351,6.501)
28	351	13.36/302	LN(1.531,2.165), B(13.83,29.78,.6537,.5262)
29	278	7.707/197	LN(1.419,1.579), B(7.83,22.58,.7814,.4231)
30	158	12.01/116	LN(2.068,1.75), W(17.63,22.6)
31	186		LN(2.288,2.438)
32	299		LN(1.943,2.777)
33	420		LN(1.931,3.208)
34	377	3.482/271	LN(1.097,1.093), B(3.5,29.82,.4465,.4556)
35	337		LN(6.278,17.81)
36	215	7.885/159	LN(1.811,1.548), W(19.3,8.179)
37	168		LN(1.663,1.624)
38	332		LN(1.883,2.436)
39	409		LN(1.515,2.328)
40	361		LN(4.847,15.93)
41	385		LN(4.453,13.12)
42	231	12.00/171	LN(1.848,1.858), B(16.45,23.05,3.777,1.152)
43	205		LN(1.622,2.038)
44	355		LN(1.258,1.735)
45	391		LN(1.307,2.167)
46	393	3.359/309	LN(.967,1.242), B(3.41,29.75,.1606,.1361)
47	304		LN(3.23,8.164)
48	231	10.21/164	LN(2.579,4.351), B(11.8,26.98,1.016,.4016)
49	276		LN(1.933,5.744)

FULDA: 500 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	154		B(.64,45.07,.5043,1.376)
2	190	5.744/138	B(.37,5.56,.4562,1.248), LN(14.49,8.946)
3	291	3.261/178	B(.33,3.23,.319,.6613), LN(6.962,3.253)
4	291	3.262/194	B(.33,3.25,.4391,1.259), LN(9.009,5.611)
5	286		LN(3.646,5.548)
6	71		B(.7,13.44,.5192,.8379)
7	114		LN(9.334,18.04)
8	147		LN(4.54,8.031)
9	206	3.614/156	B(.3,3.59,.4188,1.163), LN(7.823,3.723)
10	217	3.744/164	B(.3,3.72,.3965,1.024), LN(11.02,7.053)
11	202	2.649/154	B(.36,2.57,.6387,1.243), B(2.74,18.67,.2914,.6004)
12	86		B(.66,13.95,.4919,.9194)
13	91		LN(7.668,11.89)
14	233	4.341/157	B(.32,3.53,.5695,.972), LN(10.54,4.855)
15	191		LN(2.58,3.717)
16	247	3.734/183	B(.28,3.72,.265,.6835), B(3.78,27.91,.4104,.8969)
17	212		LN(2.583,3.531)
18	43		B(.62,15.37,.2717,.5432)
19	188		B(.02,45.46,.6774,1.615)
20	179		B(.29,32.12,.4627,2.114)
21	225	3.135/167	B(.25,2.98,.4598,.9184), B(3.16,23.33,.4209,1.679)
22	250	3.635/186	B(.25,3.63,.3872,.8926), B(3.65,27.33,.3271,.7219)
23	221		LN(2.649,4.062)
24	99	9.746/71	LN(2.342,2.08), LN(14.98,1.047)
25	103		LN(12.3,24.54)
26	224		LN(5.316,12.06)
27	255	2.634/163	B(.22,2.62,.4242,.7948), B(2.69,19.53,.4058,1.349)
28	277	3.291/179	LN(1.042,1.044), B(3.32,27.86,.3114,.5992)
29	239		LN(3.298,5.022)
30	90		LN(5.419,7.468)
31	131		B(.37,34.78,.4795,1.091)
32	257		LN(5.028,10.97)
33	217		LN(4.623,8.38)
34	169	12.55/146	LN(2.744,4.785), B(23.31,28.01,.3188,.384)
35	221	3.154/148	B(.22,3.1,.4735,1.125), B(3.41,23.69,.4814,.7061)
36	80		LN(6.748,8.535)
37	167	17.78/99	B(.31,16.93,.5454,1.188), LN(24.53,4.19)
38	221		LN(6.072,16)
39	237	3.666/146	B(.14,3.64,.6052,.8572), B(3.76,28.35,.3041,.9583)
40	304	16.08/277	B(.13,12.94,.4722,1.796), B(23.14,28.84,1.673,.781)
41	187		LN(3.405,7.143)
42	54		LN(7.314,13.18)
43	109		B(.18,29.79,.3803,.8229)
44	204	23.36/177	LN(5.851,14.93), N(26.62,1.343)
45	225	8.148/135	B(.07,8.08,.3922,.964), B(8.2,32.38,.3337,.4091)
46	204	25.94/184	LN(5.685,13.36), LN(28.66,.3565)
47	134		LN(6.597,22.13)
48	59	9.250/25	B(.21,8.86,.4167,1.297), B(10.96,27.33,.7636,.387)
49	114	12.87/93	B(.02,12.15,.3973,.972), B(22.23,30,.782,.3534)

FULDA: 500 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	93		LN(3.727,4.03)
2	176		LN(3.018,4.33)
3	267	3.590/199	B(.33,3.59,.3628,.9705), LN(10.98,7.554)
4	320	3.440/221	B(.33,3.44,.553,1.333), B(3.45,28.32,.4641,.3821)
5	281	2.544/165	B(.39,2.544,.5233,1.597),B(2.545,19.78,.7803,.6182)
6	122	9.814/44	LN(2.152,1.487), LN(11.34,.7503)
7	88		LN(3.64,3.957)
8	138		LN(3.505,5.469)
9	202		LN(4.088,7.963)
10	262	15.00/212	LN(1.643,2.146), W(25.42,7.86)
11	252	13.31/188	LN(2.096,2.291), LN(16.95,1.795)
12	84		66,14.5,.3076,.3296)
13	68		LN(2.291,2.172)
14	183		LN(2.757,4.26)
15	207	2.645/133	B(.28,2.645,.1919,.6209), LN(6.325,3.67)
16	252	22.15/200	LN(4.847,11.25), B(22.22,29.44,.4989,.5328)
17	278	14.16/210	LN(2.101,2.753), LN(17.9,1.547)
18	82	9.283/48	LN(1.749,1.07), W(14.74,14.07)
19	125	16.00/64	LN(2.957,2.918), LN(22.05,2.042)
20	178		LN(2.726,3.503)
21	222	3.969/183	B(.25,3.969,.3885,1.111), LN(8.906,5.114)
22	277		LN(4.17,9.545)
23	268	14.00/222	LN(2.392,3.912), W(18.8,1927)
24	152	13.09/78	LN(2.691,2.734), B(14.53,17.27,.4105,.9979)
25	67		LN(2.229,1.778)
26	192		LN(1.972,2.225)
27	251	3.356/207	B(.22,3.26,.3915,1.093), LN(7.324,3.85)
28	291		LN(4.22,10.11)
29	238		LN(6.192,18.09)
30	111	13.00/60	LN(1.753,1.345), W(17.56,22.2)
31	99		LN(1.871,1.476)
32	213		LN(1.79,2.395)
33	211		LN(2.338,4.014)
34	315	16.00/281	LN(1.498,1.97), W(27.55,14.65)
35	285		LN(3.904,8.973)
36	110	14.94/72	LN(2.022,1.999), W(23.21,18.87)
37	81		LN(1.43,1.222)
38	196		LN(2.034,2.428)
39	217		LN(1.384,1.748)
40	303		LN(2.954,6.58)
41	231	14.94/189	LN(1.753,2.619), W(23.37,18.7)
42	119	19.35/79	LN(3.965,5.238), B(20.25,22.52,.5161,.4252)
43	60		LN(1.377,1.632)
44	170		LN(.9519,.873)
45	208		LN(1.179,1.619)
46	212		LN(3.077,8.306)
47	159		LN(2.9,8.291)
48	101		B(.22,26.19,.2603,.378)
49	128		LN(2.004,5.724)

FULDA: 750 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	110		B(.64,45.07,.4533,.9446)
2	185	4.254/107	G(2.795,.5858), B(4.27,31.44,.8978,1.752)
3	217	3.623/136	B(.33,3.59,.2476,.6958), G(2.614,3.976)
4	248	3.876/165	B(.34,3.44,.8439,1.793), LN(11.95,8.362)
5	187	2.854/111	B(.39,2.78,.4785,1.099), B(2.89,20.1,.5573,.8519)
6	62		B(.82,12.95,.6467,.7046)
7	91		LN(10.02,17.88)
8	136		LN(8.003,17.35)
9	175		LN(4.249,8.169)
10	197	3.748/123	B(.39,3.56,.4439,1.065), B(3.78,20.1,.7316,.9051)
11	155	2.841/48	LN(.5109,.1427), LN(7.226,10.83)
12	64		B(.68,13.53,.4252,.6067)
13	68		B(.56,45.1,.3766,.7127)
14	158		G(.9703,7.869)
15	167		LN(4.778,10.12)
16	201	3.685/130	LN(1.184,1.146), B(4.38,27.52,.4704,.9619)
17	149		LN(3.549,5.36)
18	43		B(.6,15.45,.2116,.3828)
19	142		B(.02,45.46,.6284,.837)
20	128		LN(8.206,20.47)
21	184		LN(5.598,13.49)
22	222	3.704/128	G(1.631,.7092), B(3.73,27.88,.6848,1.304)
23	139		LN(4.83,8.336)
24	55		LN(4.312,5.953)
25	68	6.567/27	B(.61,5.98,.4206,.6617), B(7.24,42.31,.729,.9117)
26	185	4.181/87	B(.25,3.92,.6012,1.062), B(4.23,31.7,.5769,.8164)
27	209		LN(5.741,13.77)
28	190	14.76/149	LN(3.298,6.56), N(23.15,3.73)
29	135		LN(5.357,10.46)
30	53		LN(6.125,6.57)
31	109	15.97/44	B(.38,13.5,.3959,.8278), B(16.03,36.75,.797,1.387)
32	128		LN(6.47,14.42)
33	197		LN(4.076,7.883)
34	191	7.32/106	LN(2.022,3.257), B(7.87,28.71,.3531,.3703)
35	158	21.31/135	LN(2.41,3.6), LN(22.88,.7231)
36	64		LN(6.19,10.04)
37	106	10.31/33	B(.29,9.04,.3823,1.293), N(21.01,5.882)
38	174	20.00/138	B(.17,13.51,.5169,1.898), B(22.86,31.89,.7245,1.348)
39	177		LN(8.274,27.04)
40	195		B(.15,29.17,.317,.6317)
41	110	14.41/88	LN(2.152,2.791), B(16.3,25.08,1.155,.6274)
42	45	18.99/31	LN(3.041,4.558), B(20.28,22.72,.9149,.7744)
43	70	21.31/40	B(.12,13.77,.2853,.3836), B(23.32,29.79,.949,3.359)
44	113	22.29/74	B(.13,20.11,.3918,1.003), LN(25.88,1.058)
45	147	16.19/109	B(.07,14.81,.2682,.702), B(20.52,32.31,2.939,2.171)
46	110		B(.1,29.55,.3042,.4769)
47	71		LN(8.7,39.79)
48	25	5.606/11	B(.36,3.95,.2103,.3995), LN(3.253,5.365)
49	60		B(.02,30,.1828,.2427)

FULDA: 750 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	53		LN(2.556,1.856)
2	132		LN(3.034,4.412)
3	210	4.039/153	B(.33,4.039,.3311,.9105), LN(8.037,4.334)
4	277	19.88/223	LN(2.586,4.238), W(26.0,11.67)
5	239	12.82/162	LN(2.188,2.926), LN(15.57,1.672)
6	102	9.666/35	LN(2.531,2.552), LN(11.56,.8443)
7	62		LN(3.348,3.957)
8	118		LN(3.271,4.344)
9	184	1.900/95	LN(.577,.3351), LN(4.38,2.358)
10	218	3.974/151	B(.3,3.62,.4586,1.664),B(4.16,29.69,.6904,.6029)
11	214	12.86/159	LN(1.809,2.032), LN(16.84,1.39)
12	89	6.751/37	LN(1.336,.7214), W(13.58,8.914)
13	37		LN(3.562,3.603)
14	103		LN(3.157,4.172)
15	167		G(1.85,1.088)
16	237		LN(5.649,14.9)
17	182	13.21/131	LN(1.979,2.654), LN(17.66,1.759)
18	85		B(.62,15.87,.1605,.198)
19	104	18.83/49	LN(3.193,3.288), LN(21.69,1.857)
20	131		LN(2.261,2.483)
21	158		LN(2.179,3.179)
22	263	14.36/244	LN(1.672,2.321), B(14.59,28.47,.3687,.2498)
23	185	12.67/134	LN(2.331,3.296), W(18.36,16.91)
24	110	13.05/27	LN(1.59,1.158), B(14.53,17.34,.2695,.8964)
25	47		G(.7353,2.345)
26	130		LN(1.728,2.325)
27	178		LN(2.144,3.107)
28	226		LN(3.869,9.107)
29	151	14.07/117	LN(2.59,3.433), LN(19.9,1.378)
30	85	10.98/38	LN(1.6,1.137), W(17.5,11.3)
31	48		LN(1.656,1.165)
32	119		LN(1.851,2.164)
33	176		LN(1.655,2.14)
34	216		LN(2.365,4.584)
35	196		LN(3.714,8.408)
36	95	17.94/68	LN(2.588,2.665), W(19.84,35.33)
37	36		LN(1.713,2.167)
38	170		LN(1.325,1.246)
39	140		LN(1.306,1.519)
40	220		LN(1.626,2.605)
41	112		LN(4.176,10.04)
42	91	19.00/55	LN(2.945,3.913), LN(21.45,.7079)
43	24		LN(1.657,1.218)
44	78		G(.3207,2.407)
45	128		LN(.9447,1.251)
46	114		LN(1.07,1.493)
47	87		LN(2.506,5.74)
48	48	13.00/29	LN(2.881,4.092), LN(24.49,.8366)
49	60		LN(1.621,5.113)

FULDA: 1000 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	99		B(.71,45.07,.6888,.8734)
2	172		B(.39,39.08,.3874,1.601)
3	178	4.039/110	LN(1.266,1.12), B(5.13,30,.3785,.7041)
4	222	3.78/145	B(.33,3.74,.5004,1.427), B(4.88,27.93,.4272,.5921)
5	148		LN(4.107,7.394)
6	47		B(.72,12.83,.2988,.4626)
7	68		B(.64,44.51,.426,.5758)
8	134		B(.35,36.14,.3117,.9975)
9	119	8.603/73	LN(1.726,2.246), B(8.73,29.36,.2759,.4576)
10	184	3.785/113	LN(1.25,1.069), N(21.23,8.574)
11	124		LN(5.249,10.11)
12	43		LN(4.502,5.61)
13	53		B(.55,44.99,.9352,.7149)
14	137		B(.34,39.15,.3621,1.03)
15	160	22.57/143	LN(3.825,7.769), B(26.56,30,.6019,1.153)
16	169	3.93/101	LN(1.423,1.402), G(3.831,3.835)
17	105	3.276/77	B(.34,3.07,.4023,1.362), B(3.45,20.89,.3819,.4573)
18	18		B(.66,15.45,.2957,.594)
19	126	12.99/47	G(.9012,2.725), B(14.54,45.46,.4386,.5009)
20	135		B(.29,40.15,.5275,1.14)
21	161	3.969/108	LN(1.309,1.493), B(4.13,30,.8518,.6926)
22	129	4.33/66	LN(1.276,1.183), B(4.61,28.75,.734,.7459)
23	111	3.394/73	LN(.9306,.6926), B(3.46,21.9,.2825,.3313)
24	40		LN(4.551,6.743)
25	60		B(.46,38.6,.4191,.7264)
26	115		B(.28,33.52,.3631,.6423)
27	162		LN(7.609,21.18)
28	138	7.268/74	LN(1.361,1.364), B(7.81,28.38,.6248,.5626)
29	112	19.11/99	LN(3.238,5.629), B(19.19,22.25,.1572,.1892)
30	55		LN(7.901,12.83)
31	81	16.65/13	LN(2.609,3.252), B(17.23,38.36,.5501,.7438)
32	91		LN(12.53,32.65)
33	135		LN(10,36.49)
34	109	12.72/74	B(.19,12.52,.343,.7246), B(13.92,29.43,1.298,.5872)
35	76		LN(5.196,8.75)
36	44		LN(8.233,17)
37	74	5.673/24	LN(1.479,1.323), LN(22.83,5.473)
38	105	15.01/58	LN(4.607,7.948), B(21.09,34.78,.7466,1.181)
39	133	16.44/79	LN(6.823,25.12), LN(28.49,1.605)
40	86		B(.16,29.27,.447,.4841)
41	74	21.85/54	LN(2.397,2.848), B(22.36,25.46,.5114,.6038)
42	20		G(1.204,6.804)
43	44	22.66/13	LN(7.079,16.12), B(23.32,27.1,.5938,1.339)
44	68	24.04/26	B(.07,16.71,.3441,.6861), B(24.4,28.04,.6874,.9984)
45	60		B(.06,31.37,.3264,.4328)
46	30		B(.19,29.77,.7499,.5251)
47	42	8.85/28	B(.14,7.47,.3782,.6514), B(24.22,26.27,.8511,.616)
48	18		LN(6.805,17.75)
49	21	11.86/8	LN(1.764,8.289), B(18.78,29.58,.3444,.0925)

FULDA: 1000 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	36		LN(2.461,2.41)
2	126		LN(2.289,2.538)
3	174		LN(2.6544,3.755)
4	259		LN(5.926,15.55)
5	199	12.32/147	LN(2.065,2.577), LN(15.34,1.572)
6	96	9.657/34	LN(2.503,2.406), N(11.54,.8567)
7	30		LN(1.696,1.26)
8	119		LN(2.133,2.661)
9	117		LN(2.546,3.22)
10	196	21.86/169	LN(2.586,4.674), W(26.61,13.7)
11	160	14.65/129	LN(2.067,2.558), LN(16.4,1.338)
12	68	10.83/25	LN(2.894,3.353), LN(13.56,.975)
13	22		LN(3.198,4.233)
14	115		LN(2.232,2.85)
15	132		LN(1.85,2.162)
16	191		LN(4.528,10.94)
17	175	16.13/123	LN(2.786,4.229), LN(17.83,1.421)
18	61	13.33/30	LN(4.723,6.403), W(.7751,14.91)
19	78	18.70/33	LN(2.079,1.491), LN(21.63,1.902)
20	105		LN(1.559,1.707)
21	130		LN(2.164,3.244)
22	162	19.00/148	LN(2.123,2.736), B(22.36,26.57,.0448,.0581)
23	149		LN(5.389,12.89)
24	106	10.14/26	LN(3.423,4.205), B(14.53,17.34,.2374,.8119)
25	30		LN(1.518,1.139)
26	72		LN(1.385,1.401)
27	126		LN(2.136,2.653)
28	172		LN(1.879,2.837)
29	128		LN(3.458,6.508)
30	82	15.53/48	LN(2.715,3.25), W(17.41,43.85)
31	38		LN(2.088,2.004)
32	72		LN(1.01,.7382)
33	114		LN(1.685,2.073)
34	131		LN(1.434,1.946)
35	110	14.00/96	LN(1.65,2.265), B(15.83,21.52,.2845,.2165)
36	82	17.00/57	LN(1.676,1.407), W(.6539,19.27)
37	23		LN(1.793,2.013)
38	81		LN(.7954,.7706)
39	106		LN(1.046,1.189)
40	114		LN(1.064,1.247)
41	63		LN(3.425,7.75)
42	37		LN(10.35,28.55)
43	11		LN(1.116,.8814)
44	33		G(.3238,2.195)
45	50		G(.2914,2.472)
46	38		G(.2037,2.674)
47	49		LN(1.027,1.326)
48	35	17.00/15	G(.4718,2.259), B(22.93,25.41,.4329,.5709)
49	21		G(.4793,1.501)

PLAINS: 50 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	160		B(.66,45.06,.3999,1.194)
2	214	4.941/137	B(.37,4.94,.4786,1.27), LN(10.58,5.332)
3	275		LN(2.567,3.41)
4	233		LN(2.83,4.208)
5	201		LN(3.749,5.422)
6	49		LN(2.894,2.293)
7	119	10.64/68	LN(2.222,1.869), B(11.92,35.7,.4524,.408)
8	210		LN(7.217,13.72)
9	219		LN(3.251,4.96)
10	105		LN(3.119,5.072)
11	137		LN(3.449,5.001)
12	51		B(.66,13.82,.4182,1.673)
13	79		LN(9.708,20.35)
14	189		LN(6.506,15.13)
15	272		LN(4.354,8.742)
16	238		LN(2.527,4.432)
17	93		B(.35,17.28,.399,1.29)
18	47		LN(3.934,4.227)
19	212		B(.51,43.08,.4245,1.1)
20	201		LN(7.784,19.01)
21	316		LN(5.137,12.26)
22	221		B(.25,15.54,.3877,2.468)
23	103		LN(4.429,7.819)
24	73		LN(5.835,8.438)
25	184	10.77/117	LN(3.171,3.449), B(10.85,41.69,.9528,1.085)
26	240	5.210/153	B(.26,5.1,.504,1.307), B(5.23,39.86,.8624,1.578)
27	274	3.614/156	B(.22,3.58,.4225,1.026), B(3.62,30.77,.3623,1.149)
28	253	2.555/165	B(.22,2.52,.3922,1.29), B(2.58,18.9,1.012,2.294)
29	116		LN(4.225,8.364)
30	69		LN(4.859,6.911)
31	244		B(.38,35.56,.5124,1.622)
32	278	4.258/123	B(.21,4.16,.484,1.501), B(4.28,36.64,.8353,2.66)
33	275	3.499/177	B(.18,3.48,.3684,.8197), B(3.51,30.05,.2625,.9148)
34	260	3.364/180	B(.18,3.25,.4302,1.038), B(3.6,25.65,.9022,1.205)
35	138		LN(6.057,15.86)
36	99		LN(6.196,9.076)
37	206	19.41/161	B(.27,19.34,.7585,1.51), LN(22.6,2.468)
38	212	2.614/92	B(.15,2.55,.8801,1.436), LN(6.726,3.706)
39	203		LN(4.609,12.0)
40	200		LN(6.42,19.86)
41	189		LN(5.21,12.34)
42	82		LN(4.988,10.27)
43	128		LN(7.353,11.46)
44	192		B(.06,28.04,.4935,2.139)
45	234	9.581/191	LN(2.916,7.533), B(12.33,25.45,1.146,1.756)
46	156	14.25/121	LN(2.676,7.725), LN(17.55,2.123)
47	225		LN(6.027,21.3)
48	95		B(.13,26.98,.4257,.655)
49	281	3.338,137	LN(.8381,2.204), B(3.53,29.96,.6199,.637)

PLAINS: 50 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	71		LN(3.475,3.679)
2	151		LN(3.604,5.616)
3	237		LN(4.682,9.115)
4	257	8.140/191	B(.33,8.14,.4142,1.802), LN(23.05,5.401)
5	279	11.53/204	LN(2.297,2.56), B(13.15,20.43,.8699,1.458)
6	146	8.681/37	LN(3.16,2.538), W(11.78,19.2)
7	61		G(3.528,1.406)
8	120		LN(3.559,5.882)
9	204		LN(3.298,6.104)
10	189	21.89/163	LN(2.084,3.219), LN(25.26,1.784)
11	169	13.01/116	LN(2.193,2.616), LN(17.03,1.821)
12	132	10.83/39	LN(2.817,2.761), LN(13.06,.7446)
13	44		LN(2.527,2.077)
14	123		LN(2.625,3.867)
15	254		LN(2.71,4.485)
16	253	11.10/212	LN(1.434,1.671), B(11.12,29.14,.9195,.4287)
17	130	12.00/97	LN(2.42,2.952), LN(18.37,1.26)
18	86	11.00/26	LN(1.149,.4934), LN(14.17,.8124)
19	164	14.00/86	LN(2.163,1.927), LN(21.7,1.997)
20	140		LN(2.41,3.03)
21	288	3.500/253	B(.25,3.49,.4733,1.506), LN(13.32,5.536)
22	229	15.00/196	LN(1.512,2.1), W(27.45,14.49)
23	142	14.12/96	LN(2.175,2.674), LN(19.2,1.716)
24	160	13.00/61	LN(2.656,2.658), B(13.1,17.28,.1845,.7957)
25	104		LN(1.717,1.233)
26	149		LN(2.051,2.269)
27	262		LN(3.359,7.468)
28	241	12.00/203	LN(1.14,1.395), LN(26.15,2.186)
29	131	16.00/84	LN(2.502,3.706), LN(20.07,1.638)
30	110	13.00/52	LN(2.826,3.188), U(16.22,18.93)
31	121		LN(1.442,1.199)
32	173		LN(1.334,1.615)
33	284		LN(3.104,7.683)
34	276	15.00/229	LN(1.033,1.45), W(27.69,20.58)
35	162	15.00/122	LN(1.462,2.162), LN(22.09,1.246)
36	147	15.00/82	LN(1.932,1.567), W(19.58,47.23)
37	110		LN(1.139,.9308)
38	139		LN(1.158,1.423)
39	250		LN(2.564,5.604)
40	228	15.00/178	LN(1.966,4.185), LN(27.3,.866)
41	207		LN(4.463,12.44)
42	117	19.66/82	LN(2.249,3.04), LN(21.47,.6111)
43	116		LN(1.315,1.48)
44	183		LN(1.285,2.106)
45	261		LN(1.637,3.101)
46	224		LN(5.321,22.67)
47	247	19.00/217	LN(1.338,2.356), LN(25.95,.7626)
48	122	19.00/79	LN(1.867,2.184), LN(24.67,.8118)
49	254		LN(.9652,2.398)

PLAINS: 100 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	141	29.97/92	B(.64,28.75,.644,1.68), N(39.02,4.613)
2	203		B(.39,42.53,.3226,.9734)
3	232	11.36/163	B(.33,9.04,.53,1.302), B(11.58,29.73,.5353,.6579)
4	241		LN(4.292,9.02)
5	138		B(.4,18.82,.3394,1.244)
6	50		B(.72,10.79,.686,1.632)
7	186		B(.6,45.01,.5531,.7449)
8	224	5.703/120	B(.35,5.68,.4257,1.188), B(5.77,43.17,.7379,1.1)
9	141		LN(5.499,11.67)
10	187		LN(4.615,9.095)
11	93		B(.37,16.03,.5346,1.329)
12	47		LN(3.724,2.984)
13	74		B(.55,45.1,.6755,.8789)
14	194		B(.32,38.31,.4566,1.367)
15	178	3.409/93	B(.28,3.37,.4038,1.136), LN(9.238,5.832)
16	197		LN(3.926,6.523)
17	69		B(.34,17.1,.2962,.8271)
18	40		B(.74,15.23,.5817,1.189)
19	175	17.05/105	B(0,16.97,.5161,.4086), B(18.15,45.46,1.294,1.546)
20	191		B(.29,38.47,.4411,1.493)
21	139		B(.26,23.28,.4442,1.703)
22	166		LN(4.206,6.563)
23	106		B(.3,17.82,.327,1.246)
24	43		LN(4.244,5.578)
25	150	15.44/61	B(.42,14.8,.4512,.565), B(16.05,40.48,.5572,1.413)
26	145		B(.26,32.84,.4821,1.264)
27	110	4.429/61	B(.22,4.4,.4319,.5627), LN(9.154,4.469)
28	137		LN(6.416,12.87)
29	93		LN(5.135,12.04)
30	44		LN(3.984,5.754)
31	99	15.15/32	B(.5,14.66,.3631,.4886), LN(21.85,4.218)
32	128		B(.22,26.06,.52,1.086)
33	103		B(.18,29.82,.5605,1.326)
34	148		LN(7.458,24.73)
35	107		LN(5.216,13.76)
36	32		LN(6.162,7.927)
37	102	20.78/52	B(.35,20.71,.7408,.4975), LN(23.08,3.059)
38	87	3.857/23	LN(.8608,.955), B(4.35,26.04,.4054,.87)
39	88		B(.15,26.2,.5575,1.716)
40	112	3.899/69	LN(1.05,1.248), B(4.99,26.45,1.048,.4699)
41	112		LN(7.377,20.86)
42	28		LN(8.386,25.37)
43	34		N(17.28,8.976)
44	66		LN(11.11,35.13)
45	108		B(.05,30.43,.3438,.6153)
46	103	16.51/69	LN(2.385,8.083), LN(23.61,28.85)
47	96		B(.13,27.13,.2824,.607)
48	11		B(.23,25.58,.1611,.1246)
49	81	4.303/20	LN(.5426,1.53), B(9.4,29.94,.9344,.7281)

PLAINS: 100 FEET MASKED

Cell	Entries	Split	Distribution(s)
1	48		LN(2.02,1.579)
2	136		LN(2.142,2.394)
3	193	7.490/148	LN(1.596,1.57), B(7.72,28.97,.2061,.1996)
4	265	12.00/211	LN(1.405,1.392), LN(24.19,2.528)
5	188	12.00/129	LN(1.682,1.779), LN(16.87,1.724)
6	127	8.000/21	LN(2.639,2.001), LN(11.41,.7591)
7	40		LN(2.168,1.955)
8	104		LN(3.065,4.521)
9	149		LN(4.497,10.19)
10	181	11.00/150	LN(1.585,1.895), W(25.82,10.52)
11	116		B(.38,21.08,.2144,.4106)
12	96	8.000/37	G(.8411,2.972), LN(12.85,.7159)
13	42		LN(2.498,2.742)
14	140		LN(1.812,2.104)
15	147	3.846/113	LN(1.076,.8698), LN(13.56,7.949)
16	201	14.00/164	LN(1.225,1.268), LN(24.7,1.928)
17	126	12.00/76	LN(1.908,1.86), LN(18.4,1.743)
18	49		B(.74,15.87,.2603,.2648)
19	114	11.00/45	LN(2.04,1.739), LN(21.33,1.594)
20	123		LN(1.852,2.218)
21	140		LN(4.287,10.1)
22	166	12.00/132	LN(1.234,1.324), LN(25.91,2.173)
23	115	13.00/71	LN(1.481,1.509), LN(18.92,1.597)
24	162	9.00/58	LN(2.47,1.603), B(12.17,17.34,2.809,1.641)
25	40		LN(1.374,.9276)
26	98		LN(2.007,2.669)
27	123		LN(3.595,7.121)
28	138	20.00/101	LN(2.043,3.146), LN(26.35,1.906)
29	103	13.00/63	LN(1.431,1.758), W(20.58,11.39)
30	123	14.00/57	LN(3.236,3.63), U(16.22,18.8)
31	29		LN(1.985,2.16)
32	90		LN(1.519,1.939)
33	126		LN(3.695,8.397)
34	167	18.00/128	LN(2.131,3.893), LN(26.05,.9326)
35	119		LN(3.605,8.165)
36	76	14.00/46	LN(2.106,1.791), W(.0579,19.04)
37	34		LN(1.162,1.075)
38	68		LN(.9279,.9228)
39	104		LN(1.981,3.685)
40	140	18.00/115	LN(2.036,4.147), LN(26.5,.6802)
41	132		LN(6.239,18.39)
42	55	18.00/26	LN(2.394,3.294), U(20.25,22.28)
43	28		LN(1.377,1.497)
44	67		LN(1.132,1.885)
45	138		LN(1.362,2.357)
46	112		LN(1.549,2.501)
47	93		LN(2.1,4.682)
48	45	12.00/26	LN(1.629,1.725),LN(23.69,.3824)
49	72		LN(.6506,1.114)

PLAINS: 250 FEET UNMASKED

Cell	Entries	Split	Distribution(s)
1	138	12.63/48	B(.68,12.11,.9101,.2197), LN(38.65,4.332)
2	38	17.93/42	LN(5.504,9.687), B(18.03,41.37,.4936,1.094)
3	71		B(.34,29.67,.5184,.5708)
4	92		B(.33,28.97,.3613,.9715)
5	36		B(.43,16.21,.2768,.4048)
6	9	3*	
7	54	17.72/10	N(12.4,.319), LN(36.75,3.724)
8	54		B(.37,40.78,.5547,.7575)
9	56		B(.33,29.68,.3396,.4857)
10	65		B(.3,27.57,.2876,.7227)
11	25		LN(7.57,10.47)
12	7	3*	
13	15	7*	
14	44		B(.34,35.43,.8793,.8418)
15	50		B(.28,27.45,.2206,.2996)
16	57		B(.29,29.17,.4075,.7332)
17	25		LN(7.951,12.66)
18	2	3*	
19	95	7*	
20	8	2*	
21	55		B(.25,27.02,.203,.4567)
22	55		LN(12.79,39.18)
23	25		LN(10.41,18.65)
24	1	3*	
25	7	*	
26	5	2*	
27	38		B(.23,27.86,.2218,.2637)
28	33		LN(14.09,68.33)
29	37		B(.27,20.7,.1694,.2979)
30	5	3*	
31	28	*	
32	3	2*	
33	15	4*	
34	38		LN(20.69,180.6)
35	22	6*	
36	NO DATA POINTS		3*
37	23	*	
38	NO DATA POINTS		2*
39	10	4*	
40	18	5*	
41	9	6*	
42	NO DATA POINTS		3*
43	NO DATA POINTS		*
44	NO DATA POINTS		2*
45	11	4*	
46	18	5*	
47	12	6*	
48	NO DATA POINTS		3*
49	1	*,2*,3*,4*,5*,6*,7*	

PLAINS: 250 FEET UNMASKED ADJUSTED DATA CELLS

*: CELLS 25,31,37,43,49 COMBINED
2*: CELLS 20,26,32,38,44,49 COMBINED
3*: CELLS 6,12,18,24,30,36,42,48,49 COMBINED
4*: CELLS 33,39,45,49 COMBINED
5*: CELLS 40,46,49 COMBINED
6*: CELLS 35,41,47,49 COMBINED
7*: CELLS 13,19 COMBINED

Cell	Entries	Split	Distribution(s)
*	110	6.06/40	B(0,2.87,.0413,.5344)
		17.34/49	B(13.16,14.76,1.339,.3773), B(30.89,42.42,1.367,1.084)
2*	59		N(19.65,5.675)
3*	17		B(17.11,31.92,.1693,.2964)
4*	37		B(.13,30.43,1.088,.2503)
5*	37		B(.11,29.95,.2223,.1691)
6*	44		B(.26,27.45,.9519,.7232)
7*	25		B(.62,20.93,1.012,2.109)

```
****************************************************
****************************************************
**                                                **
** INSUFFICIENT DATA FOR 500, 750, AND 1000 FEET **
** TERRAIN MODEL DEVELOPMENT                      **
**                                                **
****************************************************
****************************************************
```

PLAINS: 250 FEET MASKED ADJUSTED DATA CELLS

Cell	Entries	Split	Distribution(s)
1*	12		LN(1.494,.8729)
2*	96		LN(1.605,1.815)
3*	192		LN(4.34,7.644)
4*	222		B(.28,29.71,.1846,.4626)
5*	140	8.199/84	LN(2.533,2.572), W(16.49,6.528)
6*	86	7.247/20	LN(2.721,2.291), LN(11.75,1.422)
7*	55		B(.53,22.26,.2643,.0764)
8*	3		LN(.3626,.0777)
9*	122		LN(1.625,2.448)
10*	164		LN(6.218,26.15)
11*	80		LN(1.972,2.243)
12*	29		B(.63,19.28,.5151,.4044)
13*	1		Masked distance=.1 nautical miles in all cases
14*	1		Masked distance=.1 nautical miles in all cases
15*	48		LN(2.003,4.158)
16*	21		LN(2.083,6.341)
17*	27		LN(1.262,2.204)
18*	1		Masked distance=.1 nautical miles in all cases

1*: CELLS 1,7,13 COMBINED
2*: CELLS 2,8,14 COMBINED
3*: CELLS 3,9,15 COMBINED
4*: CELLS 4,10,16 COMBINED
5*: CELLS 5,11,17 COMBINED
6*: CELLS 6,12,18 COMBINED
7*: CELLS 19,25,31 COMBINED
8*: CELLS 20,26,32 COMBINED
9*: CELLS 21,27,33 COMBINED
10*: CELLS 22,28,34 COMBINED
11*: CELLS 23,29,35 COMBINED
12*: CELLS 24,30,36 COMBINED
13*: CELLS 37,43,49 COMBINED
14*: CELLS 38,44,49 COMBINED
15*: CELLS 39,45,49 COMBINED
16*: CELLS 40,46,49 COMBINED
17*: CELLS 41,47,49 COMBINED
18*: CELLS 42,48,49 COMBINED

```
**********************************************************
**********************************************************
**                                                      **
** INSUFFICIENT DATA FOR 500, 750, AND 1000 FEET        **
** TERRAIN MODEL DEVELOPMENT                            **
**                                                      **
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Appendix D. SITESPE/DATAFIND FORTRAN Code

This PROGRAM SAMLOS is a version of the original developed by ASD/ENSSE. The program has been modified to suit the specific purposes of this research. The point of contact for the original version of this program is given on page D2. This program was not run interactively. All inputs were made via command files using the VAX/VMS operating system. Only the main program and the subroutine written by the authors are included in this Appendix. No changes were made to the other original functions or subroutines. Associated software must be executed prior to running this program. For details contact ASD/ENSSE.

```
      PROGRAM SAMLOS
      IMPLICIT DOUBLE PRECISION (A-H), (O-Z)
      LOGICAL WFLAG,TFLAG
      INTEGER FILENUM1,FILENUMO
      CHARACTER STATUS*3, ISYS*3
      CHARACTER FORM10*80, FORM20*80
      INTEGER*2 REC, STEP
      COMMON/FILENUMS/FILENUM1,FILENUMO
      COMMON / FACTOR / PI, REM, REF, CFAC
      COMMON /DMARFC/ REC (2,3001)
      COMMON/DMA2/ FORM10,FORM20
      COMMON/ZIN/ZFAC,JZIN
C     JZIN = 0 ALLOWS INTERPOLATION OF TERRAIN BASED ON 4 CLOSEST PTS
C     JZIN = 1 USES ONLY THE CLOSEST OF 4 POINTS FOR THE FLEVATION
C     THE PROGRAM IS WIRED TO DO INTERPOLATION. A FEW CHANGES WOULD
C     NEED TO BE MADE IN THE MAIN PROGRAM & IN FUNCTION ZINTRP IF
C     INTERPOLATION OF TERRAIN DATA IS NOT DESIRED
      COMMON/ASPE/JASP,DZZ1,DZZ2,DZZ3,OOFF,ZCSD1,ZSND1,ZCSAE
      COMMON / DMA1 / CPOINT (2), FILE (2,2),STEP(2),JSTRIP
      COMMON/TRIG/XPI,XPIO2,TOXPI,RAD,RADI
      COMMON/KORD/ ALAR(360,601), ALOR(360,601)
      COMMON/TERA/ ELMET(360,601),ASK(360,601),LIOS1(360,601)
     &,LIOS2(360,601),LIOS3(360,601),LIOS4(360,601)
     &,LIOS5(360,601),LIOS6(360,601)
      COMMON /KNTR/ JR(360)
C      COMMON / LOS / PLOS1(601), PLOS2(601), PLOS3(601), PLOS4(601),
C     &PLOS5(601), PLOS6(601), CPLOS1(601), CPLOS2(601), CPLOS3(601),
C     &CPLOS4(601), CPLOS5(601), CPLOS6(601)
      COMMON / MANGL / ALST(6,32),CALST(6,32)
      COMMON / C / ISYS
      COMMON / ZELANG / REARTH
      DIMENSION RLAT(2), RLON(2), ALT(6)
      DATA JR /179*2,181*601/
      DATA NB / 0 / , NE / 0 / , NS / 0 / , NCK / 0 / , EARTHR /
     &     6378204.0 / , ETIME / 0. / , ALT / 50., 100., 250., 500.,
     &     750.,1000. / , NALT / 6 / , WFLAG / .TRUE. / , OKR / 0. / ,
     &     FMSK / 0. / , UNM / 0. / , FMPC / 0. / , UDG / 0. / , JCH / 1
     &     / , NERR / 0 /
C*************************************************************************
C****************************************************************************
C           LINE OF SIGHT FROM A GROUND SITE TO A TARGET ALONG 360
C           RADIALS.  RADIALS BEGIN AT 1 DEGREES, AND INCREMENT BY
```

```
C           1 DEGREE TO A MAXIMUM OF 360 DEGREES.  CALCULATIONS ARE
C           MADE STARTING AT .20 NM FROM THE SITE AND INCREMENT BY .05 NM
C           OUT TO THE MAXIMUM EFFECTIVE RANGE OF THE SITE.  CALCULATIONS
C           ARE MADE FOR TARGET ALTITUDES OF 50,100,250,500,750, AND 1000
C           FEET ABOVE THE TERRAIN.  LINE OF SIGHT FOR EACH POINT ON EACH
C           RADIAL IS CALCULATED AND STORED, (YES=1), (NO=0), FOR EACH
C           OF THE 6 ALTITUDES.
C           THE PROGRAM DRAWS UPON SUBROUTINES AND ALGORITHMS ORIGINALLY
C           DEVELOPED FOR PROGRAM MASK TO READ AND ACCESS DMA TERRAIN DATA.
C
C  C     DMA:  THESE ARE A SERIES OF SUBROUTINES USED TO READ THE
C           BINARY DMA DATA FROM AN INPUT MAG. TAPE.  THE ROUTINES
C           READ THE HEADER RECORD ON THE FILE AND SETUP COMMON
C           AREAS FOR DATA STORAGE.
Comment  DMA RECORDS USED ARE I*2, NOT I*4
C*******************************************************************
C
C   CREATION DATE:     FEB 1985, DAVE RICHART, ASD/ENSSE
C                      AV 785-7181, 513-255-7181
C                      ASSISTED BY JORDAN WESCOTT,ASD/ENSSE
C   REVISION DATE:     AUG 1985, HAMILTON/JOHNSON, AFIT/ENA
C******************************************************************
C
C
C
C           FILE MANAGEMENT SECTION ........
C
      TFLAG=.TRUE.
      CALL CPUTIM(TFLAG)
      REARTH = 8504272.0
C     THE VALUE USED FOR REARTH SHOULD BE CHANGED DEPENDING ON WHAT
C     PORTION OF THE EARTH IS INVOLVED. THE VALUE IN METERS IS 4/3 ACTUAL
C     VALUE IN METERS.
      CFAC=100./(2.54*12.)
      IJZNIT=0
      JZNIT=9
      JZIN=0
      JASP=0
      JAL=0
      JZ=0
      XPI=DACOS(-1.D0)
CM    INPUT FILE
CM    FOR022.DAT = DIGITAL TERRAIN DATA INPUT FILE
CM    OUTPUT FILES ARE AS FOLLOWS:
CM    FOR004.DAT = BASIC OUTPUT FILE : ELEVATION IN METERS, MASKING ANGLE
CM    IN DEGREES, AND LINE OF SIGHT FOR EACH POINT ON EACH RADIAL BY ALTITUDE
CM    FOR024.DAT = ERROR OUTPUT FILE
CM    FOR025.DAT = PROCESSED MASK ANGLE OUTPUT FILE
CM    FOR026.DAT = PROCESSED LINE OF SIGHT OUTPUT FILE
C
      READ*, SLAD,SLAM,SLAS,SLOD,SLOM,SLOS
      READ*, ANTHZ
      READ*, FILENUMI,FILENUMO
 6    FORMAT(T2,F5.0,T12,F5.0,T22,F7.2,T32,F5.0,T42,F5.0,T52,F7.2)
 7    FORMAT(T2,F7.3)
```

```
      TOXPI=2.*XPI
      XPI02=XPI/2.
      RAD=180./XPI
      RADI=XPI/180.
      PI=XPI
      SLAR=(SLAD+SLAM/60.+ SLAS/3600.)*RADI
      SLOR=(SLOD+SLOM/60.+ SLOS/3600.)*RADI
      XDIR=0.
      DO 8 I=1,360
      CALL COORDS(SLAR,SLOR,XDIR,I,J)
 8    CONTINUE
      DO 9 J=1,601
      ALOR(180,J)=SLOR
      ALOR(360,J)=SLOR
 9    CONTINUE
COMMENT -- CHANGE ALT IN FEET TO METERS.
      DO 10 N = 1, NALT
      ALT (N) = ALT (N) * 0.3048006096
 10   CONTINUE
      CLEARZ=.20
      EFRNG=30.
COMMENT -- CHANGE CLEARZ AND EFRNG IN NAUT. MI. TO RADIANS.
      CLEARZ = ACLRZ/(60.*RAD)
      EFRNG = AEFRNG/(60.*RAD)
      ZFAC=DCOS(SLAR)
      DSTRIP=6./(3600.*RAD)
      AWEST=9999.
      AEAST=-9999.
      DO 140,IG=180,360
      AWEST=MIN(AWEST,ALOR(IG,601))
 140  CONTINUE
      DO 141, IG=1,179
      AEAST=MAX(AEAST,ALOR(IG,601))
 141  CONTINUE
      FIRST=AWEST-DSTRIP
      DLAST=AEAST+DSTRIP
COMMENT -- NOW HAVE LIMITS OF DMA DATA NEEDED. WILL READ DMA DATA
      NFPT = 1
      CALL DINIT
      CALL FOWARD (FIRST)
      ALON1 = SC2RAD(CPOINT(1))
      ALON2 = SC2RAD(CPOINT(2))
      GO TO 160
  150 CALL DMARD (ALON1, ALON2, JZ)
      IF (ALON1 .GT. ALOR(1,1) .AND. ALON2.GT.ALOR(1,1))GO TO 170
  160 DO 169 , IT=180,360
  161 IF(ALOR(IT,JR(IT)).GE.ALON1.AND.ALOR(IT,JR(IT)).LE.ALON2)THEN
           ELMET(IT,JR(IT)) = ZINTRP(ALAR(IT,JR(IT)),ALOR(IT,JR(IT)))
           JR(IT)=JR(IT)-1
           IF(JR(IT) .LT. 2) THEN
             JR(IT)=2
             IF(IT .EQ. 360) GO TO 1695
             GO TO 169
           ENDIF
           GO TO 161
```

```
      ENDIF
 169  CONTINUE
      GO TO 150
 1695 ELMET(1,1) = ZINTRP(ALAR(1,1),ALOR(1,1))
      DO 1696 IFIRST = 2,360,1
      ELMET(IFIRST,1)=ELMET(1,1)
 1696 CONTINUE
      SITEZ=ELMET(1,1)
      ANTZ=SITEZ+ANTHZ
 170  DO 179, IT = 1,179
 171  IF(ALOR(IT,JR(IT)).GE.ALON1.AND.ALOR(IT,JR(IT)).LE.ALON2)THEN
           ELMET(IT,JR(IT)) = ZINTRP(ALAR(IT,JR(IT)),ALOR(IT,JR(IT)))
           JR(IT)=JR(IT)+1
           IF(JR(IT) .GT. 601) THEN
             JR(IT)=601
             GO TO 179
           ENDIF
           GO TO 171
      ENDIF
 179  CONTINUE
 180  CALL DMARD(ALON1,ALON2,JZ)
      IF(ALON1 .GT. DLAST .AND. ALON2 .GT. DLAST) GO TO 200
 190  DO 199, IT = 1,179
 191  IF(ALOR(IT,JR(IT)).GE.ALON1.AND.ALOR(IT,JR(IT)).LE.ALON2)THEN
           ELMET(IT,JR(IT)) = ZINTRP(ALAR(IT,JR(IT)),ALOR(IT,JR(IT)))
           JR(IT)=JR(IT)+1
           IF(JR(IT) .GT. 601) THEN
             JR(IT)=601
             GO TO 199
           ENDIF
           GO TO 191
      ENDIF
 199  CONTINUE
      GO TO 180
C     NOW HAVE ALL THE ELEVATION VALUES FOR SAMLOS.  WILL NOW CALCULATE
C     MASKING ANGLES AND LINE OF SIGHT FROM SAM SITE TO ALL TARGET
C     POSITIONS AND ALTITUDES BY RADIAL.
 200  CONTINUE
      DO 219 ITE=1,360
        RANGE = .20/(60.*RAD)
        ITES=5
        ASK(ITE,ITES)=ELANG(ELMET(ITE,ITES),ANTZ,RANGE)
        DO 2999 IZ=1,5,1
        LIOS1(ITE,IZ)=1
        LIOS2(ITE,IZ)=1
        LIOS3(ITE,IZ)=1
        LIOS4(ITE,IZ)=1
        LIOS5(ITE,IZ)=1
        LIOS6(ITE,IZ)=1
 2999 CONTINUE
        SPMASK=ASK(ITE,ITES)
        DO 209 ITES=6,601
          RANGE=RANGE+.05/(60.*RAD)
          ASK(ITE,ITES)=ELANG(ELMET(ITE,ITES),ANTZ,RANGE)
          ASK(ITE,ITES)=MAX(SPMASK,ASK(ITE,ITES))
```

```
          SPMASK=ASK(ITE,ITES)
            IALT=1
            TARELA=ELANG((ELMET(ITE,ITES)+ALT(IALT)),ANTZ,RANGE)
            IF(TARELA.GE.SPMASK) THEN
              LIOS1(ITE,ITES)=1
              GO TO 2020
            ENDIF
            LIOS1(ITE,ITES)=0
            IALT=2
            TARELA=ELANG((ELMET(ITE,ITES)+ALT(IALT)),ANTZ,RANGE)
            IF(TARELA.GE.SPMASK) THEN
              LIOS2(ITE,ITES)=1
              GO TO 2030
            ENDIF
            LIOS2(ITE,ITES)=0
            IALT=3
            TARELA=ELANG((ELMET(ITE,ITES)+ALT(IALT)),ANTZ,RANGE)
            IF(TARELA.GE.SPMASK) THEN
              LIOS3(ITE,ITES)=1
              GO TO 2040
            ENDIF
            LIOS3(ITE,ITES)=0
            IALT=4
            TARELA=ELANG((ELMET(ITE,ITES)+ALT(IALT)),ANTZ,RANGE)
            IF(TARELA.GE.SPMASK) THEN
              LIOS4(ITE,ITES)=1
              GO TO 2050
            ENDIF
            LIOS4(ITE,ITES)=0
            IALT=5
            TARELA=ELANG((ELMET(ITE,ITES)+ALT(IALT)),ANTZ,RANGE)
            IF(TARELA.GE.SPMASK) THEN
              LIOS5(ITE,ITES)=1
              GO TO 2060
            ENDIF
            LIOS5(ITE,ITES)=0
            IALT=6
            TARELA=ELANG((ELMET(ITE,ITES)+ALT(IALT)),ANTZ,RANGE)
            IF(TARELA.GE.SPMASK) THEN
              LIOS6(ITE,ITES)=1
              GO TO 208
            ENDIF
            LIOS6(ITE,ITES)=0
            GO TO 208
2020        LIOS2(ITE,ITES)=1
2030        LIOS3(ITE,ITES)=1
2040        LIOS4(ITE,ITES)=1
2050        LIOS5(ITE,ITES)=1
2060        LIOS6(ITE,ITES)=1
208       CONTINUE
209     CONTINUE
219   CONTINUE
      CALL DATAFIND(LIOS1,50)
      CALL DATAFIND(LIOS2,100)
      CALL DATAFIND(LIOS3,250)
```

```
      CALL DATAFIND(LIOS4,500)
      CALL DATAFIND(LIOS5,750)
      CALL DATAFIND(LIOS6,1000)
      CLOSE (22)
      TFLAG=.FALSE.
      CALL CPUTIM(TFLAG)
      GO TO 290
  280 CONTINUE
      WRITE(24,'(1H1)')
      CALL DUMP
  290 STOP
C
   30 FORMAT (I2, I4, I6, 3F5.0, 1X, 3F5.0, F6.0, F5.0, 2X, I1, F7.0, F8
     &      .0)
 240  FORMAT(' 3 C', 2(I6,2X), A3, F10.3,5X,F10.2,2X,2(F15.4,2X))
C
 991  CONTINUE
      WRITE(24,*)'CANNOT OPEN FILE FDAT UNIT 12 FOR INPUT.........'
      GO TO 999
 992  CONTINUE
      WRITE(24,*)'CANNOT OPEN FILE MASKIN UNIT 15 FOR INPUT.........'
      GO TO 999
 993  CONTINUE
      WRITE(24,*)'CANNOT OPEN FILE ALARMIN UNIT 20 FOR INPUT.........'
      GO TO 999
 994  CONTINUE
      WRITE(24,*)'CANNOT OPEN FILE ERROR UNIT 24 FOR OUTPUT.........'
      GO TO 999
 995  CONTINUE
      WRITE(24,*)'CANNOT OPEN FILE AOUT UNIT 26 FOR OUTPUT.........'
      GO TO 999
 996  CONTINUE
      WRITE(24,*)'CANNOT OPEN FILE EVENT UNIT 27 FOR OUTPUT.........'
 999  CONTINUE
      WRITE(24,*)'ERROR DUE TO OPEN ON FILE LISTED ABOVE.'
      WRITE(24,*)'MUST ABORT RUN DUE TO FILE ERROR. '
      WRITE(24,*)'PLEASE CORRECT FILE.  ERROR COULD BE:'
      WRITE(24,*)'        INCORRECT LOCAL FILE NAME'
      WRITE(24,*)'        NO INPUT FILE FOR OPEN'
      WRITE(24,*)'        OUTPUT FILE ALREADY EXISTIS'
      WRITE(24,*)'        '
      END
C
       SUBROUTINE DATAFIND(LOS, ALTITUDE)
       INTEGER ALTITUDE,RADIAL,STARTPT,STARTANG,FILENUM1,FILENUM0
       INTEGER RCA,CYCLES,LOS(360,601),MASKED,UNMASKED
       REAL XCOORD1,RANGE,DISTANCE,RCAINNM
       COMMON/FILENUMS/FILENUM1,FILENUM0
       MASKED=0
       UNMASKED=1
       FACTOR=.0174533
C
       DO 50 RCA=500,55500,500
       CYCLES=0
       RCAINNM=RCA*.00054
```

```
        RADIAL=INT(ASIN(RCAINNM/30)*57.29578)+271
4       STARTPT=RADIAL
        IF (RADIAL.LE.360 .AND. RADIAL.GE.271) STARTANG=360-RADIAL
        IF (RADIAL.GE.1 .AND. RADIAL.LE.90) STARTANG=-RADIAL
        IF (RADIAL.GE.91 .AND. RADIAL.LE.270) STARTANG=180-RADIAL
        RANGE=30
        XCOORD1=COS((450-RADIAL)*FACTOR)*RANGE
        J=INT(RANGE/.05)
        IF (LOS(RADIAL,J).EQ.1) GO TO 7
        IF (LOS(RADIAL,J).EQ.0) GO TO 8
5       J=INT(RANGE/.05)
        IF (J.GT.601) THEN
             J=601
             RANGE=30
             DISTANCE=30-ABS(XCOORD1)
          WRITE(FILENUM1,100) RCA,ALTITUDE,STARTANG,
     1        DISTANCE,UNMASKED,STARTPT
             GO TO 10
        END IF
C
7       IF (LOS(RADIAL,J).EQ.1) THEN
             RADIAL=RADIAL+1
             IF (RADIAL.EQ.361) RADIAL=1
             RANGE=RCAINNM/ABS(SIN((450-RADIAL)*FACTOR))
             GO TO 5
        ELSE
              DISTANCE=ABS(XCOORD1-COS((450-RADIAL)*FACTOR)*RANGE)
              XCOORD1=COS((450-RADIAL)*FACTOR)*RANGE
          WRITE(FILENUM1,100) RCA,ALTITUDE,STARTANG,
     1        DISTANCE,UNMASKED,STARTPT
        STARTPT=RADIAL
        IF (RADIAL.LE.360 .AND. RADIAL.GE.271) STARTANG=360-RADIAL
        IF (RADIAL.GE.1 .AND. RADIAL.LE.90) STARTANG=-RADIAL
        IF (RADIAL.GE.91 .AND. RADIAL.LE.270) STARTANG=180-RADIAL
        END IF
100     FORMAT(1X,I6,2X,I4,2X,I3,2X,F6.2,2X,I1,2X,I3)
C
6       J=INT(RANGE/.05)
        IF (J.GT.601) THEN
             J=601
             RANGE=30
             DISTANCE=30-ABS(XCOORD1)
           WRITE(FILENUM0,100) RCA,ALTITUDE,STARTANG,
     1          DISTANCE,MASKED,STARTPT
             GO TO 10
        END IF
C
8      IF (LOS(RADIAL,J).EQ.0) THEN
             RADIAL=RADIAL+1
             IF (RADIAL.EQ.361) RADIAL=1
             RANGE=RCAINNM/ABS(SIN((450-RADIAL)*FACTOR))
             GO TO 6
        ELSE
             DISTANCE=ABS(XCOORD1-COS((450-RADIAL)*FACTOR)*RANGE)
             XCOORD1=COS((450-RADIAL)*FACTOR)*RANGE
```

```
         WRITE(FILENUMO,100) RCA,ALTITUDE,STARTANG,
     1            DISTANCE,MASKED,STARTPT
           STARTPT=RADIAL
      IF (RADIAL.LE.360 .AND. RADIAL.GE.271) STARTANG=360-RADIAL
      IF (RADIAL.GE.1 .AND. RADIAL.LE.90) STARTANG=-RADIAL
      IF (RADIAL.GE.91 .AND. RADIAL.LE.270) STARTANG=180-RADIAL
      END IF
C
      IF (INT(RANGE/.05).LT.602) GO TO 5
10    CYCLES=CYCLES+1
      IF (CYCLES.NE.2) THEN
         RADIAL=INT(ASIN(RCAINNM/30)*57.29578)+91
         GO TO 4
      END IF
50    CONTINUE
C
      RETURN
      END
```

Appendix E. Factorial Analysis Graphic Results

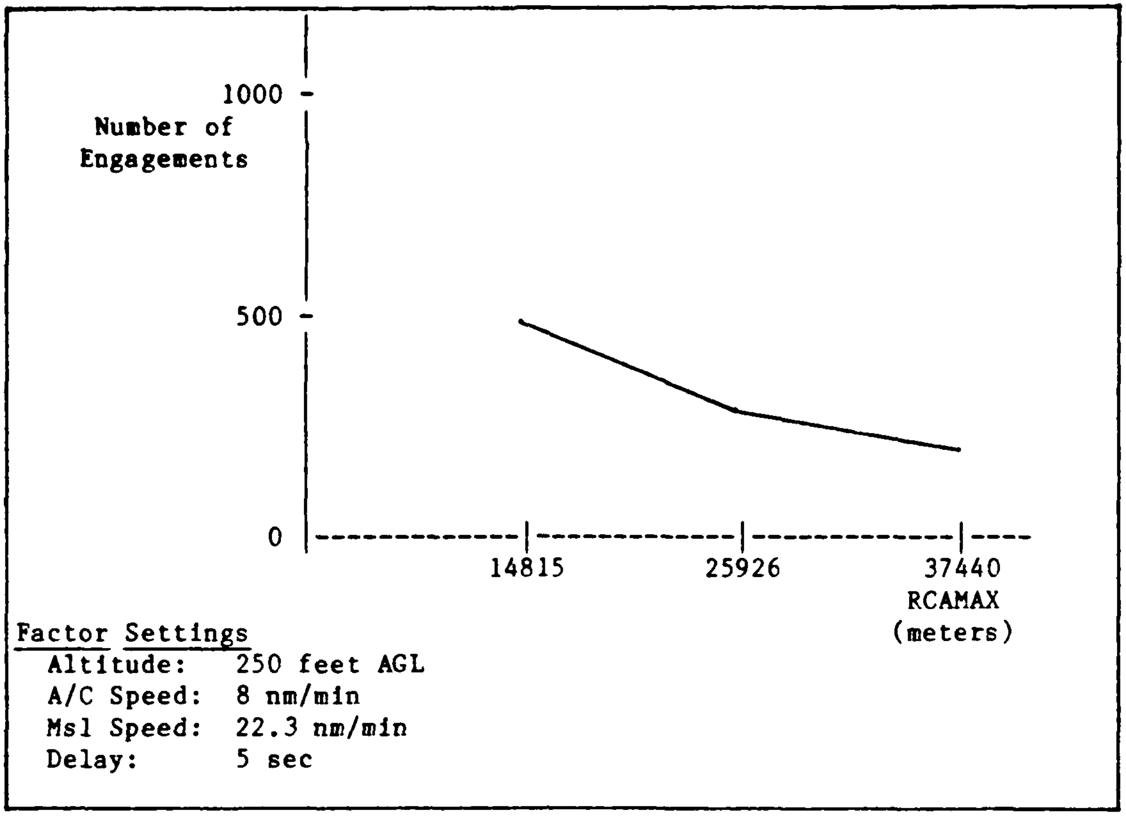


Figure E-1. Fulda Main Factors -- Number of Engagements vs. RCAMAX.

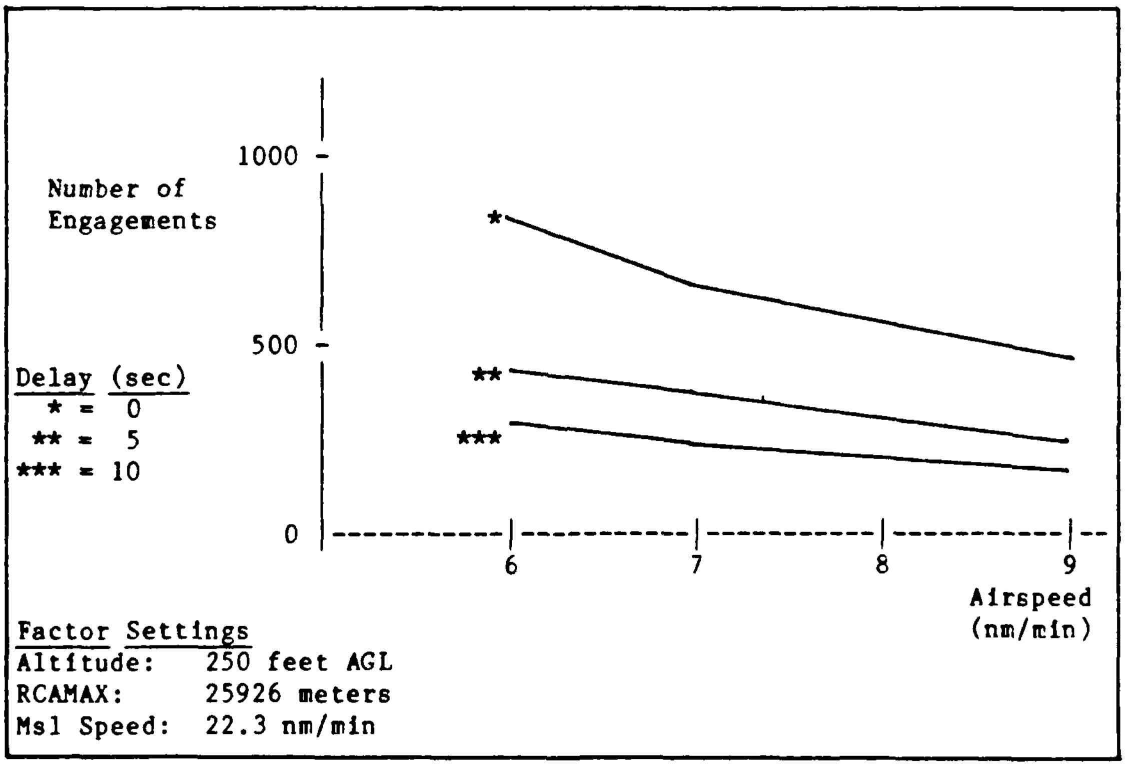


Figure E-2. Fulda Interaction -- Delay versus Aircraft Airspeed.

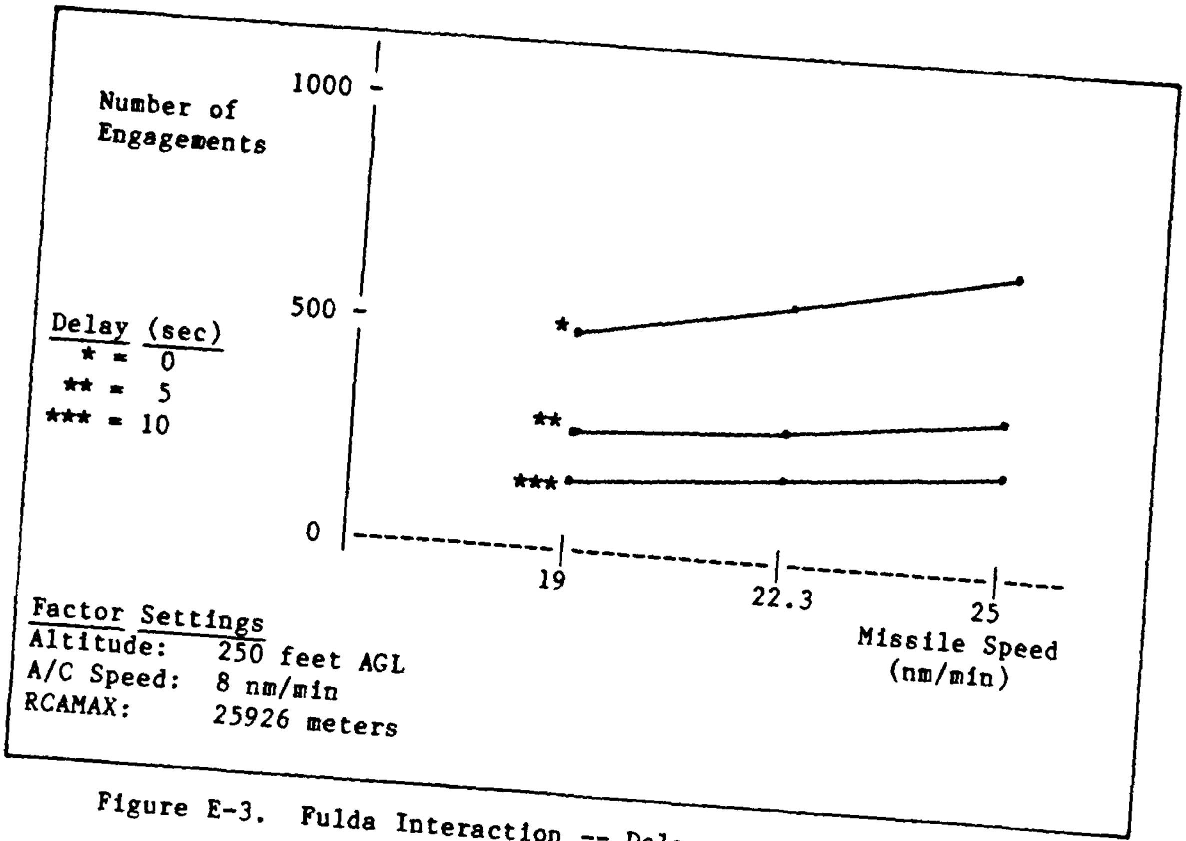


Figure E-3. Fulda Interaction -- Delay versus Missile Speed.

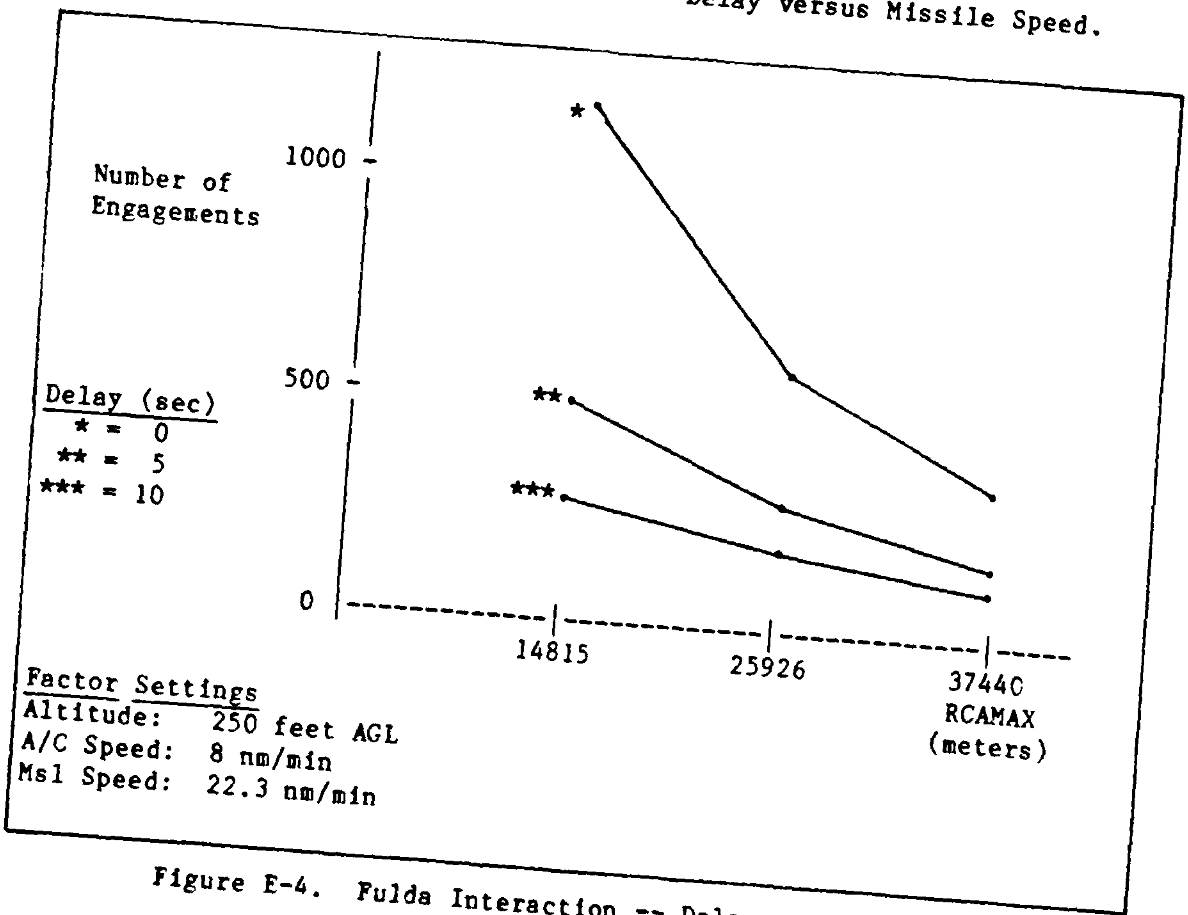


Figure E-4. Fulda Interaction -- Delay versus RCAMAX.

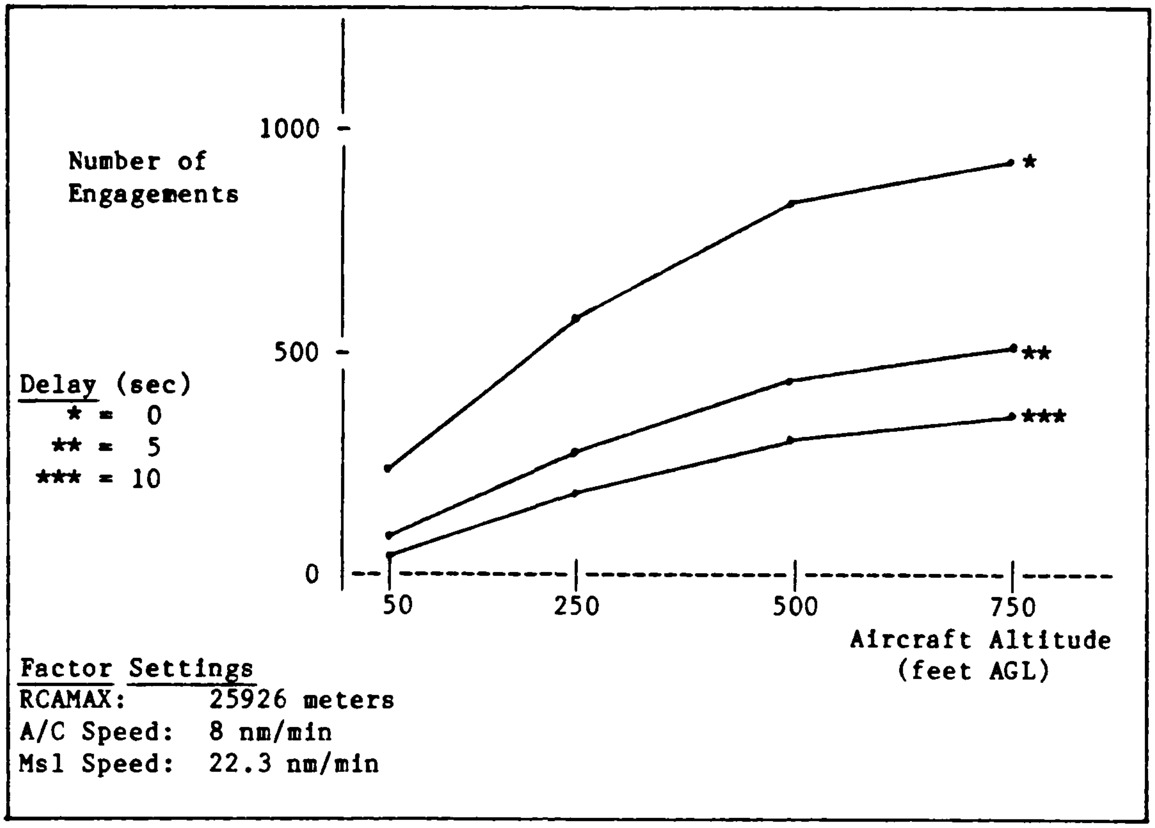


Figure E-5. Fulda Interaction -- Delay versus Aircraft Altitude.

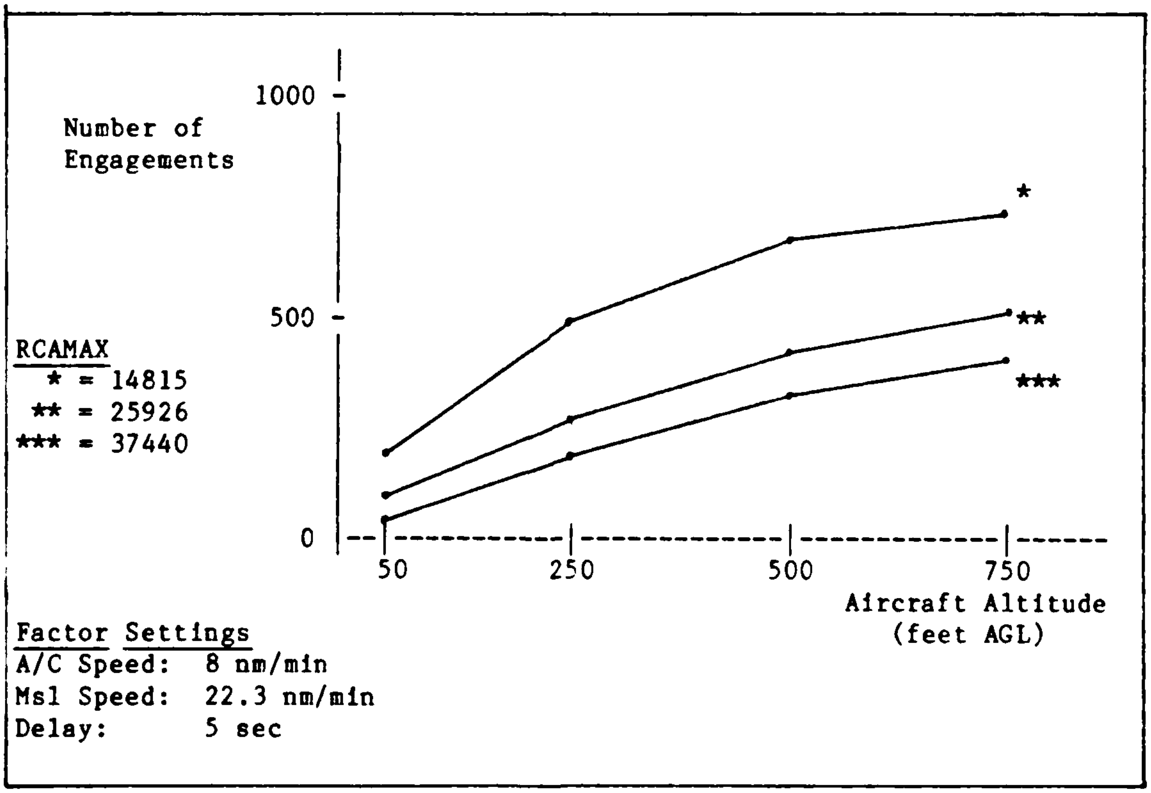


Figure E-6. Fulda Interaction -- Aircraft Altitude versus RCAMAX.

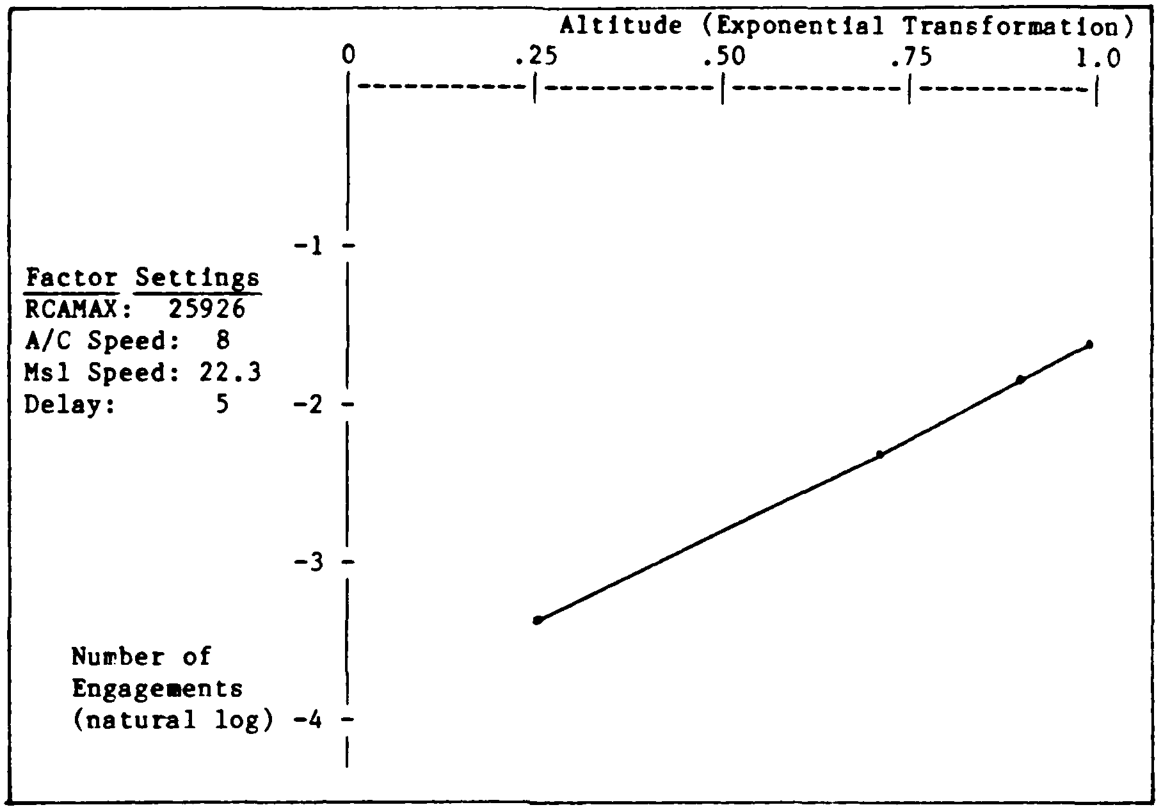


Figure E-7. Transformed Fulda Data -- Engagements versus Altitude.

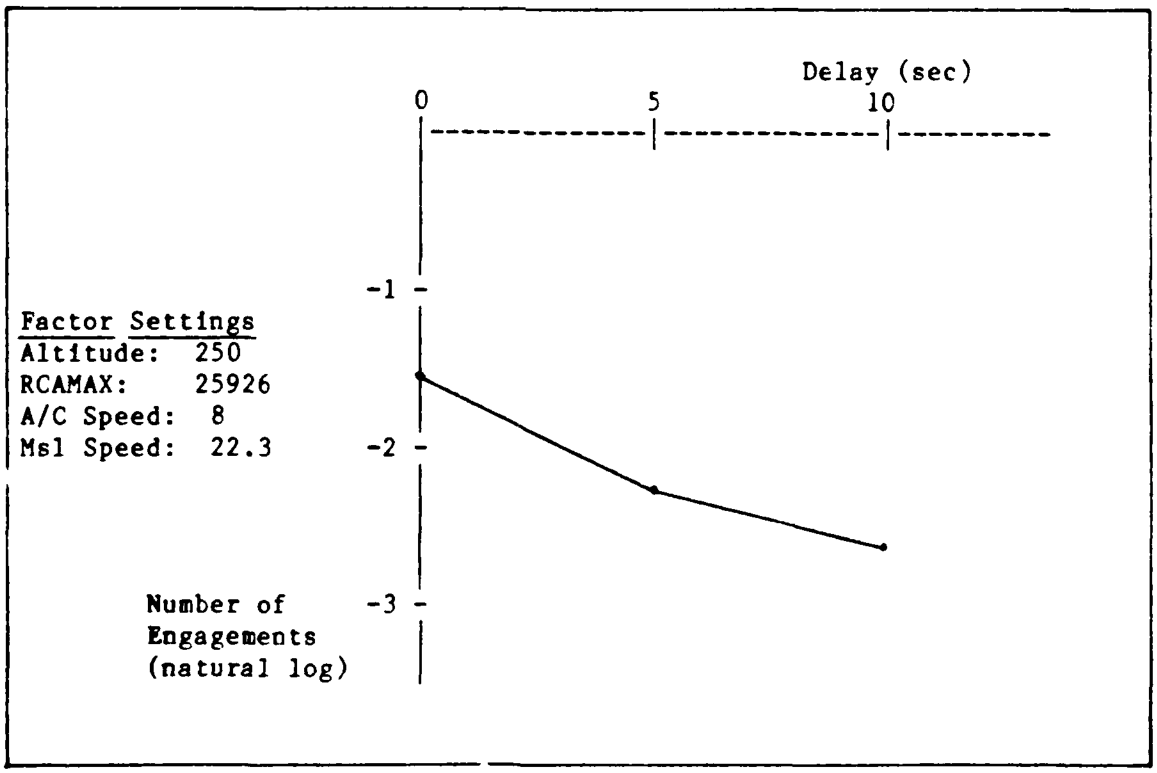


Figure E-8. Transformed Fulda Data -- Engagements versus Delay.

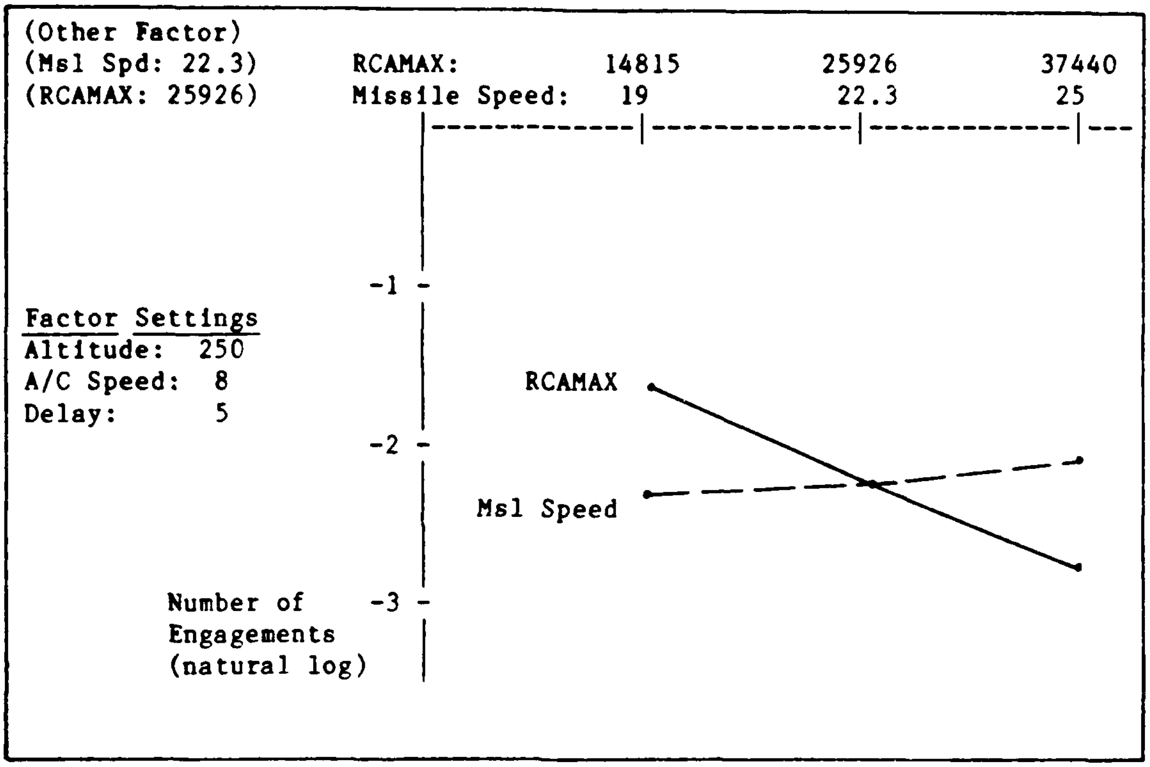


Figure E-9. Transformed Fulda Data -- Engagements versus RCAMAX and Engagements versus Missile Speed.

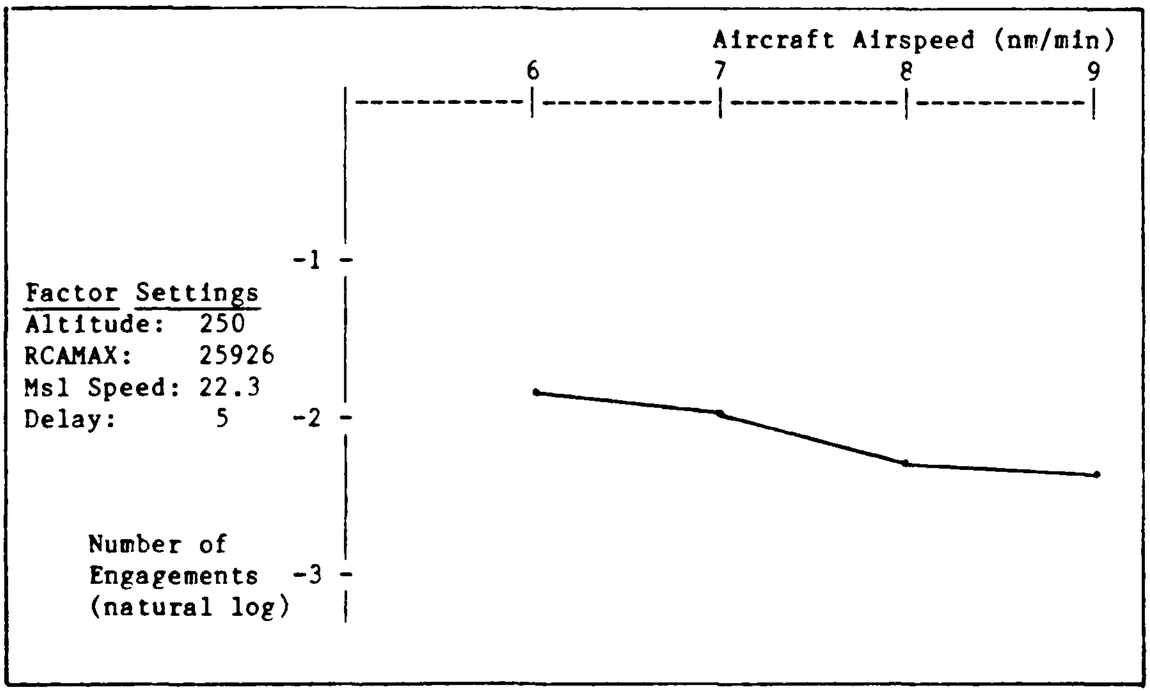


Figure E-10. Transformed Fulda Data -- Engagements versus Airspeed.

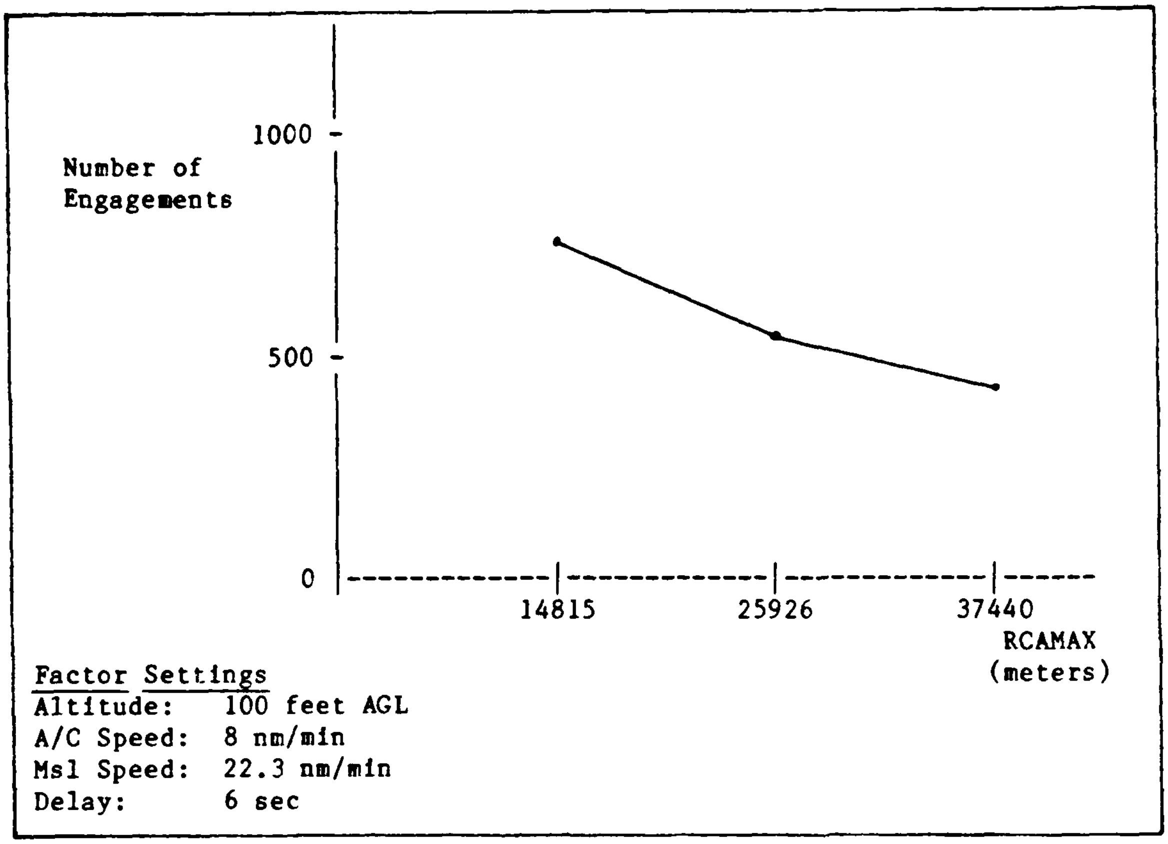


Figure E-11. Plains Main Factors -- Number of Engagements versus RCAMAX.

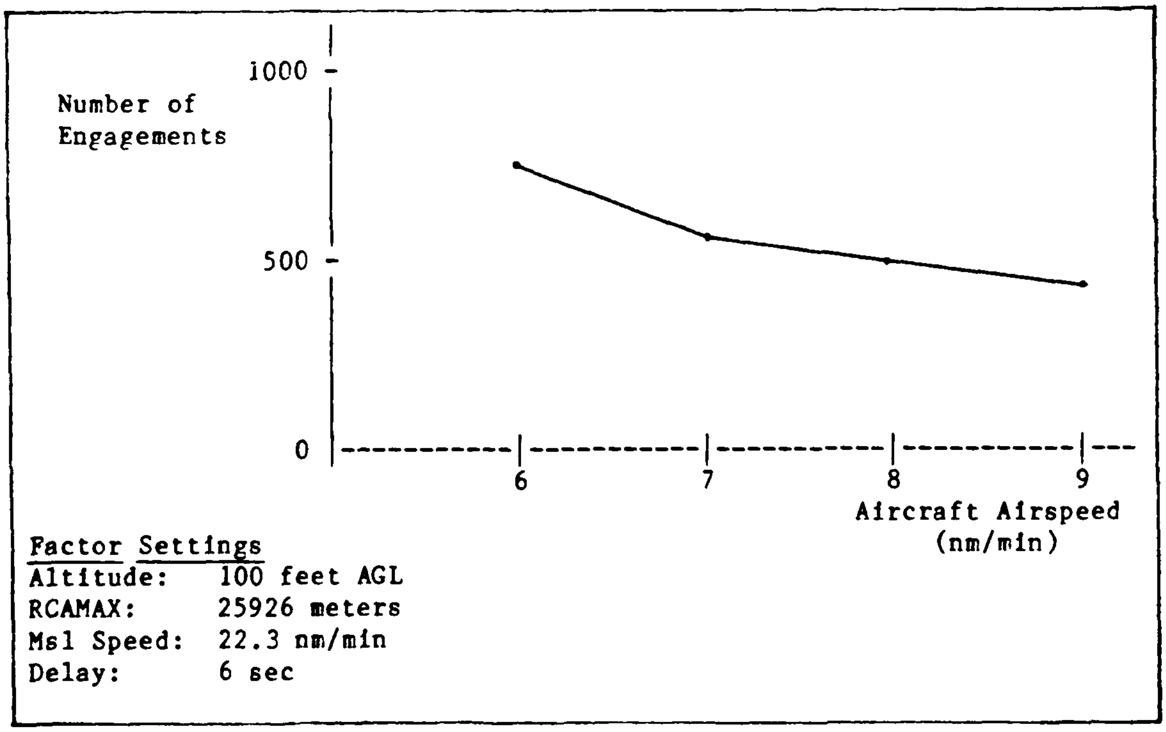
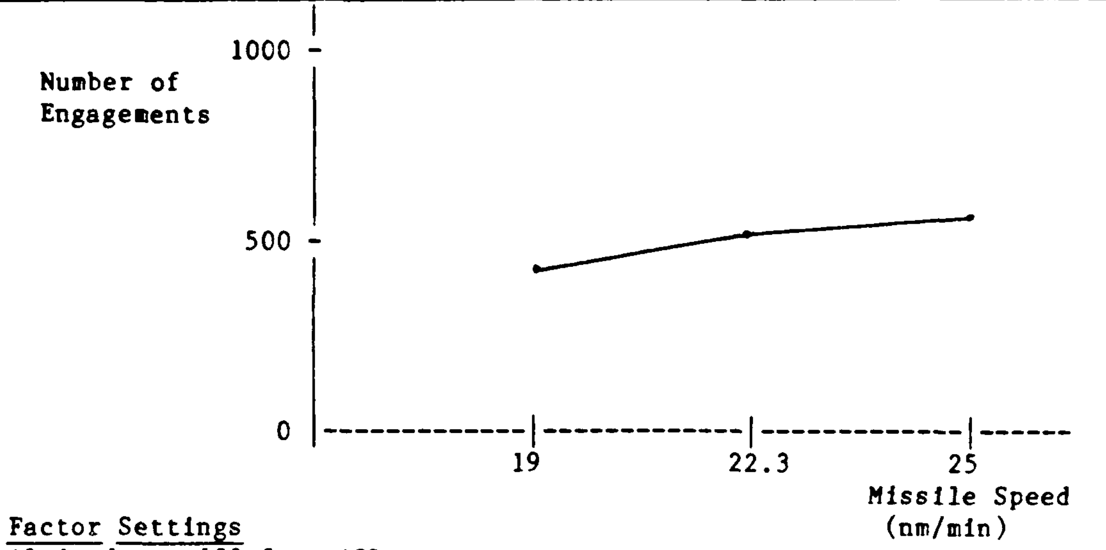
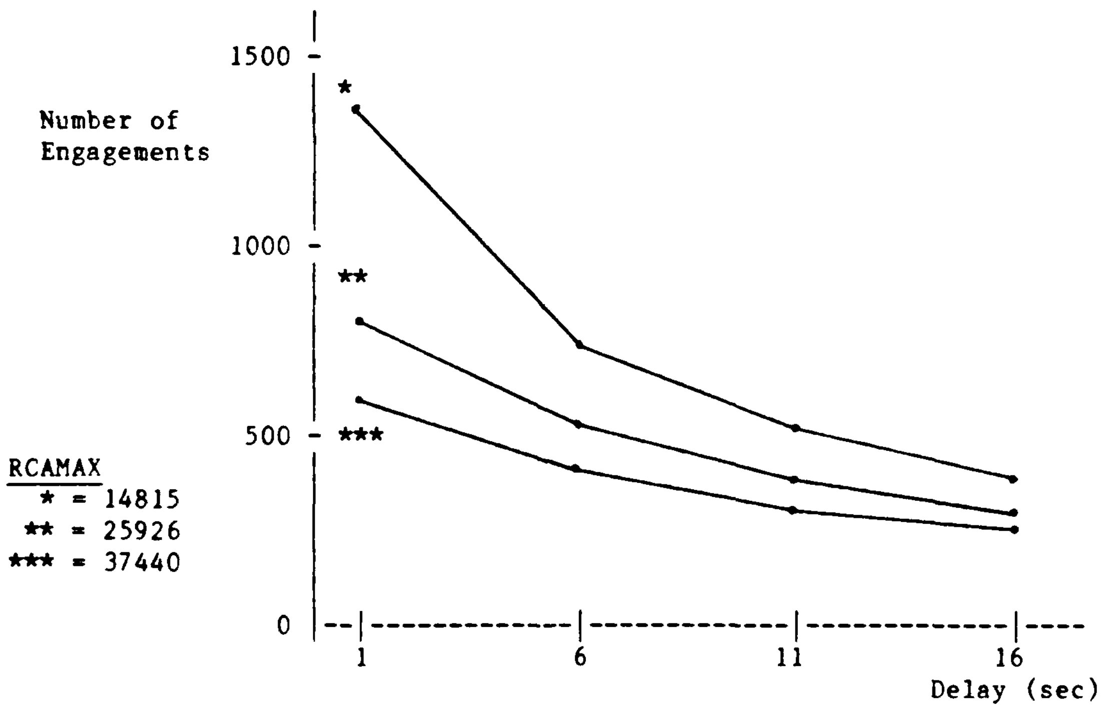


Figure E-12. Plains Main Factors -- Number of Engagements versus Speed.



Factor Settings
Altitude: 100 feet AGL
A/C Speed: 8 nm/min
RCAMAX: 25926 meters
Delay: 6 sec

Figure E-13. Plains Main Factors -- Engagements versus Missile Speed.



Factor Settings
Altitude: 100 feet AGL
A/C Speed: 8 nm/min
Msl Speed: 22.3 nm/min

Figure E-14. Plains Interaction -- Delay versus RCAMAX.

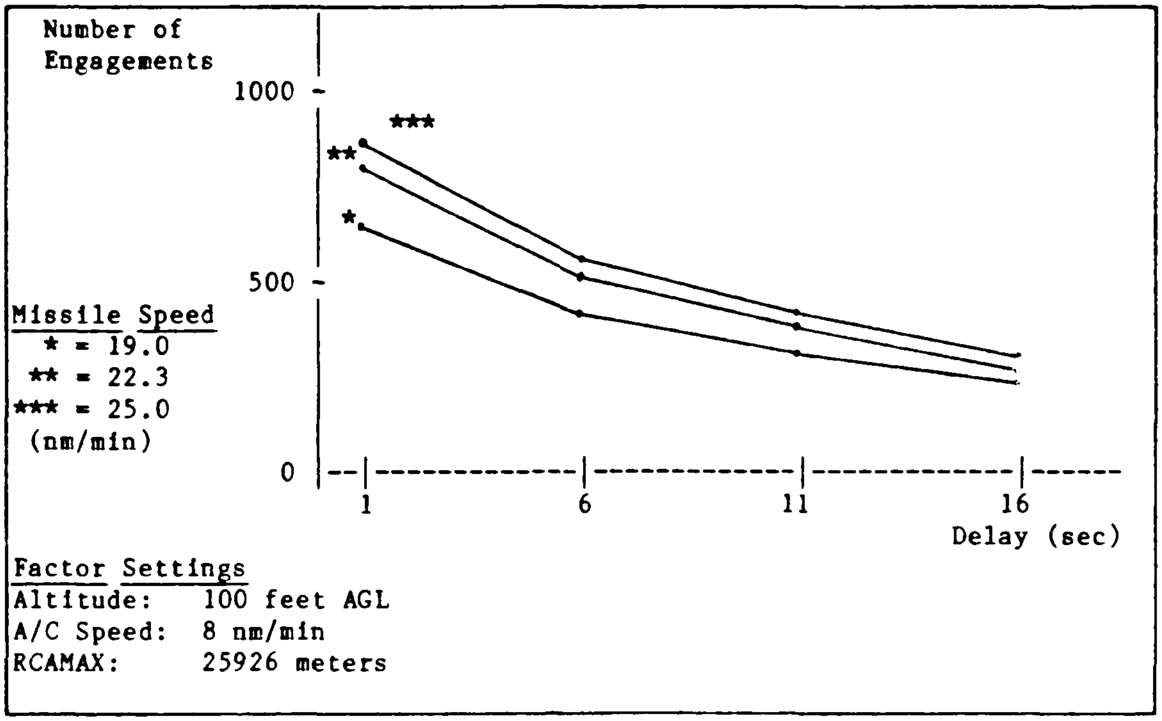


Figure E-15. Plains Interaction -- Delay versus Missile Speed.

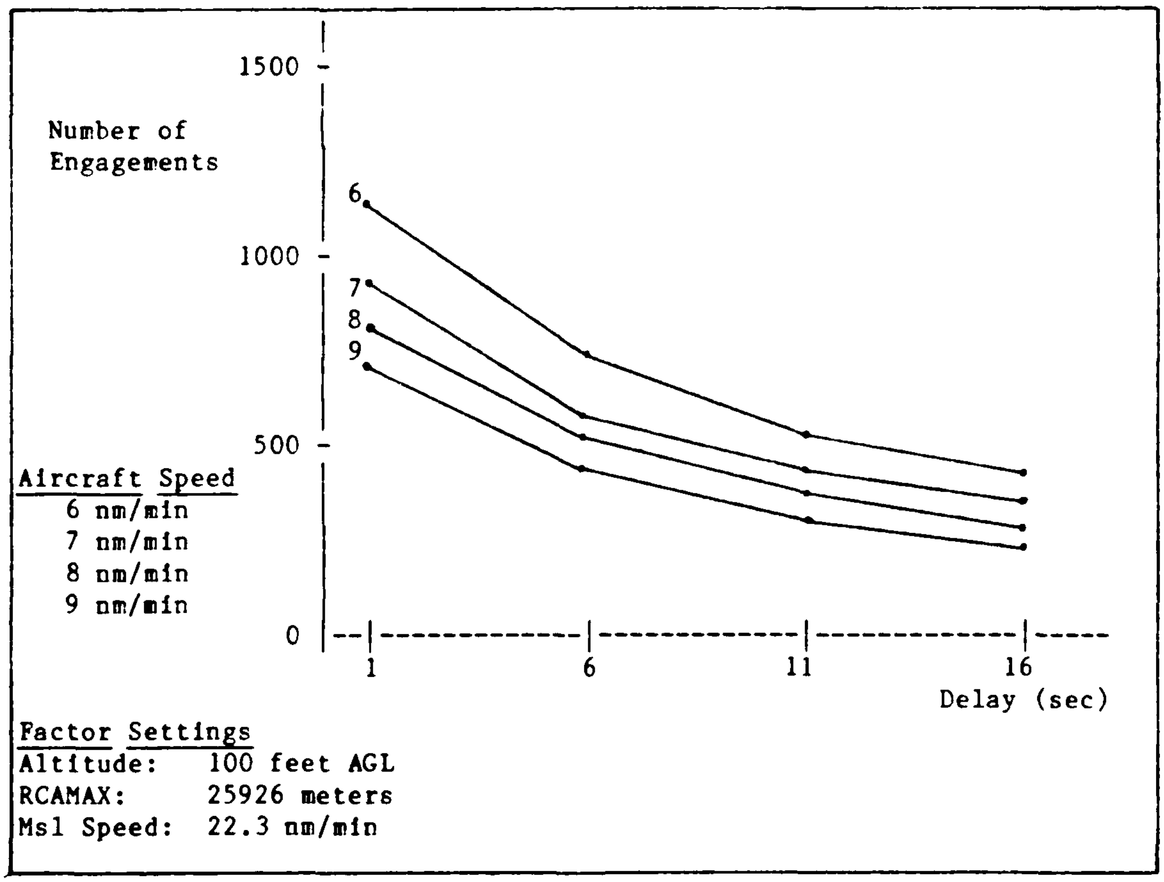
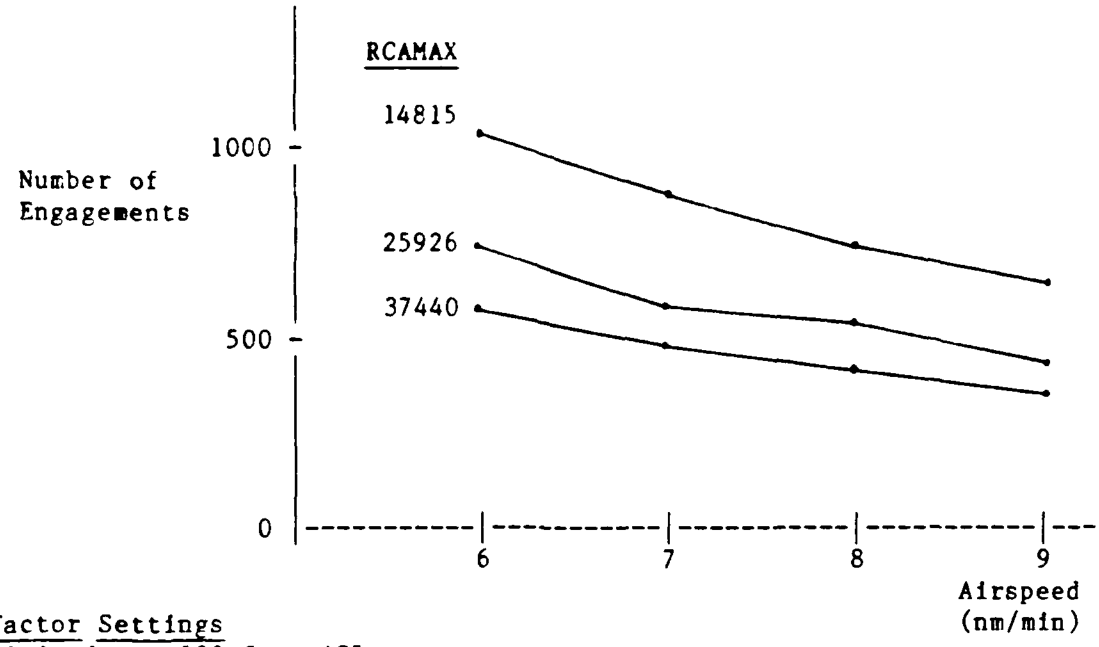
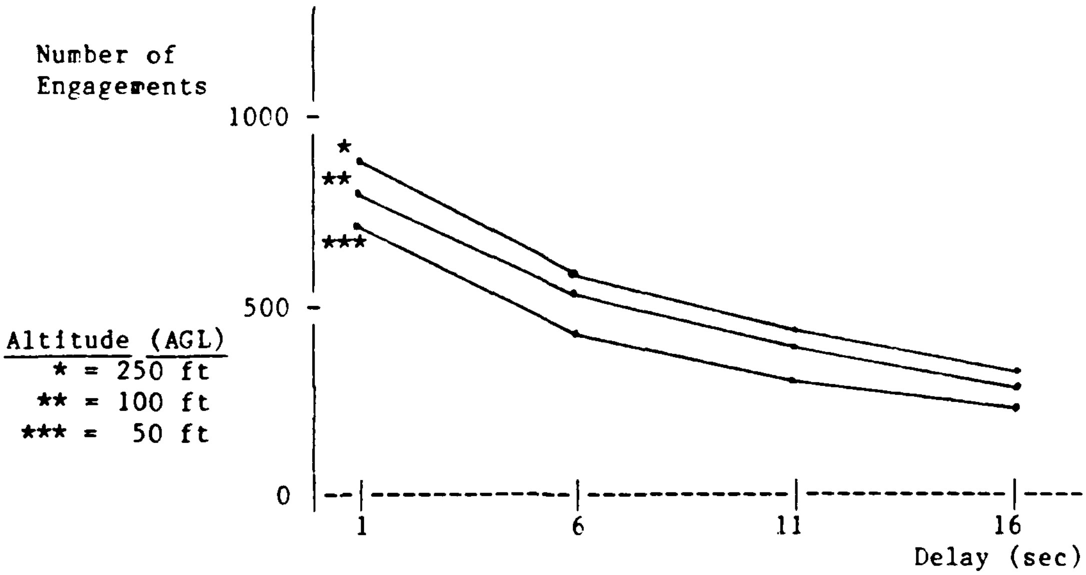


Figure E-16. Plains Interaction -- Delay versus Aircraft Speed.



Factor Settings
Altitude: 100 feet AGL
Msl Speed: 22.3 nm/min
Delay: 6 sec

Figure E-17. Fulda Interaction -- RCAMAX versus Aircraft Airspeed.



Altitude (AGL)
* = 250 ft
** = 100 ft
*** = 50 ft

Factor Settings
RCAMAX: 25926 meters
A/C Speed: 8 nm/min
Msl Speed: 22.3 nm/min

Figure E-18. Plains Interaction -- Delay versus Aircraft Altitude.

Appendix F. Fulda Terrain Model Statistics

STATISTICS FOR 'BEST' SUBSET

MALLOWS' CP	9.00
SQUARED MULTIPLE CORRELATION	0.97741
MULTIPLE CORRELATION	0.98864
ADJUSTED SQUARED MULT. CORR.	0.97727
RESIDUAL MEAN SQUARE	0.020979
STANDARD ERROR OF EST.	0.144841
F-STATISTIC	6961.90
NUMERATOR DEGREES OF FREEDOM	8
DENOMINATOR DEGREES OF FREEDOM	1287
SIGNIFICANCE (TAIL PROB.)	0.0000

NOTE THAT THE ABOVE F-STATISTIC AND ASSOCIATED SIGNIFICANCE TEND TO BE LIBERAL WHENEVER A SUBSET OF VARIABLES IS SELECTED BY THE CP OR ADJUSTED R-SQUARED CRITERIA.

VARIABLE NO.	NAME	REGRESSION COEFFICIENT	STANDARD ERROR	STAND. COEF.	T-STAT	2TAIL SIG	TOL-ERANCE	CONTRI-BUTION TO R-SQ
	INTERCEPT	-1.32785	0.0514190	-1.382	-25.82	.000		
1	altitude	1.74205	0.0187752	0.541	92.78	.000	0.516655	.15108
2	airspeed	-0.177740	0.00359859	-0.207	-49.39	.000	1.000000	.04281
6	rcamax	-0.000061369	.7200772E-6	-0.590	-85.23	.000	0.365886	.12747
7	mispeed	0.0427086	0.00163980	0.109	26.05	.000	1.000000	.01190
8	delay	-14.679	0.254764	-1.040	-57.62	.000	0.053871	.05826
9	n1	0.562586	0.0191327	0.417	29.40	.000	0.087296	.01517
10	n2	0.14685065E-6	.8702865E-8	0.083	16.87	.000	0.725077	.00500
11	n3	1.07174	0.0640144	0.227	16.74	.000	0.095607	.00492

THE CONTRIBUTION TO R-SQUARED FOR EACH VARIABLE IS THE AMOUNT BY WHICH R-SQUARED WOULD BE REDUCED IF THAT VARIABLE WERE REMOVED FROM THE REGRESSION EQUATION.

SUMMARY STATISTICS FOR RESIDUALS

(CASES WITH POSITIVE WEIGHT)	
AVERAGE RESIDUAL	-0.0000
RESIDUAL MEAN SQUARE	0.02097882
AVERAGE DELETED RESIDUAL	-0.0000
AVE. SQUARED DELETED RESIDUAL (PREDICTION MEAN SQUARE)	0.02115284
SERIAL CORRELATION	0.2155
DURBIN-WATSON STATISTIC	1.5681

25.93 IS THE MAXIMUM VALUE OF MAHALANOBIS DISTANCE AMONG CASES WITH POSITIVE CASE WEIGHT.

-7.02 IS THE LARGEST STANDARDIZED RESIDUAL (IN ABSOLUTE VALUE) AMONG CASES WITH POSITIVE CASE WEIGHT.

0.05 IS THE MAXIMUM VALUE OF COOK'S DISTANCE AMONG CASES WITH POSITIVE WEIGHT. IF THIS CASE WERE OMITTED, THE REGRESSION COEFFICIENTS WOULD MOVE FROM THE VALUES REPORTED ABOVE TO THE EDGE OF A 0.01 PERCENT CONFIDENCE ELLIPSOID.

NORMAL PROBABILITY PLOT FOR STANDARDIZED RESIDUALS

```
          .......+......+......+......+......+.......
          -                                         -
          -                                         -
E         -                                     *   -
X         -                                    */   -
P         -                                   **    -
E         -                                   *     -
C     2   +                                  *      +
T         -                                 **      -
E         -                               ***       -
D         -                              **         -
          -                             **          -
N         -                            **           -
O         -                            *            -
R     0   +                           **            +
M         -                          **             -
A         -                         **              -
L         -                        **               -
          -                       **                -
V         -                      **                 -
A         -                     **                  -
L    -2   +                   ***                   +
U         -                 ***                     -
E         -                **/                      -
          -           *  *  /                       -
          -  *       *     /                        -
          -                                         -
          .......+......+......+......+......+.......
               -6     -4     -2      0      2
```

STANDARDIZED RESIDUAL

Appendix G. Plains Terrain Model Statistics

STATISTICS FOR 'BEST' SUBSET

MALLOWS' CP	8.00
SQUARED MULTIPLE CORRELATION	0.97816
MULTIPLE CORRELATION	0.98902
ADJUSTED SQUARED MULT. CORR.	0.97798
RESIDUAL MEAN SQUARE	0.005977
STANDARD ERROR OF EST.	0.077314
F-STATISTIC	5476.31
NUMERATOR DEGREES OF FREEDOM	7
DENOMINATOR DEGREES OF FREEDOM	856
SIGNIFICANCE (TAIL PROB.)	0.0000

NOTE THAT THE ABOVE F-STATISTIC AND ASSOCIATED SIGNIFICANCE TEND TO BE LIBERAL WHENEVER A SUBSET OF VARIABLES IS SELECTED BY THE CP OR ADJUSTED R-SQUARED CRITERIA.

VARIABLE NO.	NAME	REGRESSION COEFFICIENT	STANDARD ERROR	STAND. COEF.	T- STAT.	2TAIL SIG.	TOL- ERANCE	CONTRI- BUTION TO R-SQ
	INTERCEPT	-0.416314	0.0406363	-.799	-10.24	.000		
1	altitude	0.227821	0.0367227	.094	6.20	.000	0.111613	.00098
2	airspeed	-0.146546	0.00235259	-.315	-62.29	.000	1.000000	.09901
6	rcamax	-0.000038002	.9160398E-6	-.674	-41.49	.000	0.096628	.04392
7	mispeed	0.0309886	0.00107202	.146	28.91	.000	1.000000	.02132
8	delay	-2.68344	0.0444690	-.480	-60.34	.000	0.403064	.09292
9	n1	0.0112789	0.000374097	.250	30.15	.000	0.370486	.02319
10	n2	0.156470	0.0132818	.253	11.78	.000	0.055278	.00354

THE CONTRIBUTION TO R-SQUARED FOR EACH VARIABLE IS THE AMOUNT BY WHICH R-SQUARED WOULD BE REDUCED IF THAT VARIABLE WERE REMOVED FROM THE REGRESSION EQUATION.

SUMMARY STATISTICS FOR RESIDUALS

(CASES WITH POSITIVE WEIGHT)	
AVERAGE RESIDUAL	-0.0000
RESIDUAL MEAN SQUARE	0.00597744
AVERAGE DELETED RESIDUAL	-0.0001
AVE. SQUARED DELETED RESIDUAL (PREDICTION MEAN SQUARE)	0.00603688
SERIAL CORRELATION	0.1155
DURBIN-WATSON STATISTIC	1.7677

15.90 IS THE MAXIMUM VALUE OF MAHALANOBIS DISTANCE AMONG CASES WITH POSITIVE CASE WEIGHT.

-3.51 IS THE LARGEST STANDARDIZED RESIDUAL (IN ABSOLUTE VALUE) AMONG CASES WITH POSITIVE CASE WEIGHT.

0.02 IS THE MAXIMUM VALUE OF COOK'S DISTANCE AMONG CASES WITH POSITIVE WEIGHT. IF THIS CASE WERE OMITTED, THE REGRESSION COEFFICIENTS WOULD MOVE FROM THE VALUES REPORTED ABOVE TO THE EDGE OF A 0. PERCENT CONFIDENCE ELLIPSOID.

NORMAL PROBABILITY PLOT FOR STANDARDIZED RESIDUALS

```
         ....+....+....+....+....+....+....+....+...
         -                                          -
         -                                          -
E        -                                        * -
X        -                                    **  / -
P        -                                    *   / -
E        -                                   **//   -
C    2   +                                  **/     +
T        -                                **/       -
E        -                               **         -
D        -                             ***          -
         -                           ***            -
N        -                          **              -
O        -                        /**               -
R    0   +                       **                 +
M        -                     ***                  -
A        -                  ****                    -
L        -                 **                       -
         -               ***                        -
V        -             **                           -
A        -           **/                            -
L   -2   +        ***/                              +
U        -      ***/                                -
E        -      */                                  -
         -  * *//                                   -
         - *  /                                     -
         -                                          -
         ....+....+....+....+....+....+....+....+...
                -2.4      -.80       .80       2.4
           -3.2      -1.6       0.0       1.6
```

STANDARDIZED RESIDUAL

Appendix H. Vitae

James R. Hamilton

Captain James R. Hamilton was born on 9 September 1953 in Gooding, Idaho. He graduated from high school in Mountain Home, Idaho, in 1971 and attended the United States Air Force Academy from which he received the degree of Bachelor of Science in Aeronautical Engineering in June 1975. He completed pilot training and received his wings in August, 1976. He then served as an F-4E aircraft commander in the 3rd and 313th Tactical Fighter Squadrons at Clark AFB, Philippines, and Hahn AFB, Germany. He then served as an F-4D instructor pilot and flight examiner in the 31st Tactical Training Wing at Homestead AFB, Florida, until entering the School of Engineering, Air Force Institute of Technology, in August, 1984.

Permanent Address: Route 1 Box 819
Mountain Home, Idaho 83647

Ronald G. Johnson

Major Ronald G. Johnson was born on 22 April 1951 in Superior, Nebraska. He graduated from high school in Courtland, Kansas, in 1969, and attended the United States Air Force Academy, from which he received the degree of Bachelor of Science in Political Science and International Affairs in June, 1973. He completed pilot training, and became a T-38 instructor pilot at Williams AFB, Arizona. He served as an A-10 flight commander and standardization/evaluation flight examiner at RAF Bentwaters, United Kingdom, and as an A-10 squadron scheduler and flight examiner at Davis-Monthan AFB, Arizona. He entered the School of Engineering, Air Force Institute of Technology, in August, 1984.

Permanent address: 311 Republic Street
Courtland, Kansas 66939

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The objective of this research was to develop a methodology to characterize entire terrain types in terms of their impact on the encounter between aircraft and surface-to-air missile (SAM) systems. Two contrasting types of terrain were chosen for analysis, the moderately rugged terrain around Fulda, West Germany, and the North German Plain. Digitized terrain elevation data (DTED), developed by the Defense Mapping Agency, served as raw data. Twenty suitable SAM sites were sampled from each terrain area. Four layers of data transformation were used to convert the DTED data for these sites into 49-cell terrain models. These terrain models consisted of probability distribution functions of masked and unmasked distances an aircraft would fly as it transitted a SAM system's lethal zone at various altitudes. A simulation model was then used to determine the number of completed engagements an aircraft would experience per nautical mile flown through a battle area in each terrain type. The simulation runs used five variables: aircraft altitude, aircraft airspeed, threat density, missile speed, and SAM system reaction time. A full factorial design analysis of variance was then accomplished to determine what the significant factors were, and to explain how they interacted to define terrain effects on the aircraft-SAM system encounter. Multiple regression was used to develop a single equation that predicts terrain effects in each terrain type in terms of an upper bound on the number of complete engagements possible per nautical mile. The resulting regression equations have extremely high predictive capability, and would be usable in more complex models to define the effects of terrain on the aircraft-SAM system encounter.

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